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Ideas From Future Technologies Workshop Held by ARL/TARDEC, June 1993

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CONTRIBUTING EDITOR

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13. ABSTRACT *(Maximum 200 words)*

The Future Technologies Workshop was held on 9–11 June 1993, at Aberdeen Proving Ground, MD, by the U.S. ARL in collaboration with the U.S. Army TARDEC. The objective was to determine what technologies ARL should be addressing to benefit the next fleet of armored fighting vehicles. The focus was on the structure, signatures, and armor protection of a future ground combat vehicle. ARL and TARDEC researchers provided briefings on vehicle requirements and constraints. Invitees, experts in related areas from industry, academia, and government, participated in brainstorming sessions and generated many innovative ideas. This is a report on those ideas, most directed at vehicle design, some more philosophical in nature.

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Mr. Rod Peterson
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Dr. Craig Rogers
Mr. Steve Sanders
Mr. Samuel R. (Bob) Skaggs
Dr. Z. G. Sztankay

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Any errors in the edited transcripts of the presentations are the responsibility of the contributing editor.

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1. INTRODUCTION

This is primarily a report on ideas, specifically those generated in brainstorming sessions to suggest structure, signature, and armor protection notions for a future combat vehicle. See sections 2 and 10 for details about the workshop. What we want to do here is to encourage you to peruse and consider the suggested ideas (see Tables 1–6 for a short description of each). For the sake of continuity, we have defined the numerous acronyms used throughout this report in a list on pages 113–114. Do not read this as you would a technical report. It is meant to impart ideas, some well considered, others far-out and interesting, but probably unrealistic.

There are edited transcripts of the ideas discussed at the focus sessions and presented to the group (noted by * in Tables 1–6) and summaries of one page or less provided by the proponent for most of the other ideas submitted. The ideas are organized and grouped into Structure/Armor; Signatures/Sensors; Propulsion/Energy Transformation; Lethality; Other; and, of no less importance, Philosophical Comments sections to facilitate reader digestion. The categories are not exclusive as we really wanted cross-fertilization of ideas; the categorization is done on the basis of primary emphasis. Although Propulsion/Energy Transformation, Lethality, and Other Ideas were not part of the focus, they were a natural outcome of the brainstorming. The presentations were conversational, not formalized; they were a lot of fun; unfortunately the accompanying humor and camaraderie had to be removed to keep this report manageable.

If you read nothing else, read the "Devil's Advocate" presentation (section 9). If you only read two selections, read "Management of Innovation" (section 8.1) as well.

For far-term consider such interesting armor concepts as rotating flywheels (3.6) or the Catcher's Mitt (3.7); composite energy storage cells which double as armor (3.10); smart material armors with fibrous sensors (3.11) or with active control of delamination (Table 1, No. 15); and also active mounting hardware (shape memory alloy velcro and structural/electrical connectors) (Table 1, No. 17). Or how about a pivoted pod/spoked wheel (5.6) for propulsion or the Jack Rabbit vehicle (5.7)? Or manufacturing ceramic armor in the field (3.9)?

For near-term solutions combining structure, ballistic protection, hardening for NBC, and signature management for the next combat vehicle, consider the possible combination of some of the following: the

advanced material hull with embedded protected crew (3.1); graded Z layers of fiberglass for nuclear protection (3.4); maturation and possible combination of ceramic composites and explosive reactive armor for ballistic protection (3.5); the local application of modular armor (3.8); the constraint that the vehicle fit into standard ship containers with weight limit of 45 tons (3.12); acoustic structural considerations up front in the design (4.1); passive (4.5, 4.6) and perhaps some interesting active (4.3, 4.4) signature control; advanced sensor windows (4.7); and possible composite tracks (4.8).

For propulsion, energy storage, and transformation, consider a hybrid power train (5.1); phase change materials for passive thermal energy storage (5.4); an adiabatic engine (5.2) or composite engine and transmission parts (3.3); the use of motor signature analysis (5.5) or chaotic time series analysis (5.8) to increase engine efficiency; innovative gun recoil systems (5.3). Until advances in electric power make ETC or EM more feasible, let's assume a liquid propellant gun (6.1) with reduced size (6.4), and a shorter barrel for signature reduction (4.2).

Also, is a single active protection system which defeats both KE and CE feasible (3.2)? How beneficial would laser detonation of reactive armor (6.3) be? How would it be implemented? Should steam propellant (6.5) be investigated? Could biosensors and activated spray be the NBC solution (7.1)? Should a 60-GHz radio be considered to enhance communications and reduce IR signature (7.2)? Do we need two tanks, one heavyweight that can address all threats, the other lighter weight for special deployment (Table 6, No. 11)?

Note the concern in 8.1 over the conditions which foster innovation vs. the present dependence of Tech Base programs on major Army programs in ARL. The application of multidisciplinary optimization (8.2), the need for combined efforts (8.3), and the need to systematize a technology as early as possible (8.4) are all suggested to address the integration of new technologies into a cost-effective design. Sections 8.5, and 8.7–8.9 are pleas to rethink some of the assumptions which have gone into vehicle requirements for many, many years. Note also the comments in 5.2.1 and 6.1 on the incremental approach.

Table 1. Structure/Armor Ideas

Issue No.	Issue	Proponent
1*	Advanced material hull, smooth shaped, using low-cost titanium, composites, and ceramics with heavy passive armor around crew stations. LO technology embedded into hull during manufacture when possible.	W. Haskell
2*	Evaluate a single, all-purpose APS.	R. Eichelberger
3*	Develop capability for the community to make composite engine and transmission parts, e.g. blocks, heads, connecting rods, transmission cases; also gun recoil support components.	L. Puckett
4*	Graded Z layers of fiberglass with increasing atomic number as you go deeper into the layers of material.	B. Skaggs
5	Mature and exploit two existing technologies (ceramic composites and explosive reactive armors).	D. Orphal
6	Rotating Armor—Have an array of flywheels. Provide transverse momentum mass to defeat penetration. Provide power for EM/ET armor protection. Stabilize vehicle.	D. Eccleshall
7	Moveable armor—Catcher's Mitt.	Z. G. Sztankay
8	Apply armor locally.	O. Cathey
9	Develop technology to manufacture and apply ceramic armor from locally obtained materials (sand, rock, dirt).	B. Moore
10	Multifunctional composite energy storage cells for power/electric drive armor/reactive armor.	D. Granville
11	Integrate fibers into armor for sensing, mounting, etc.	A. Akerman
12	Develop vehicles to fit into standard ship containers/weight limits.	L. Puckett
13	Investigate armor NiWCo with C, Be, Si to obtain SG 6.5 g/cm, St 100 ksi @ 1,500° F (Tough = 1/brittle = 12 ppf.)	S. Sanders
14	Develop a semiactive armor that uses no energetic material but includes "moving parts," i.e., embedded plates designed to shear or fracture the host material to dissipate energy over a larger area/volume.	C. Rogers
15	Use of active control for reducing bulges of a composite hull hit by medium to large rounds.	C. Rogers
16	Examine use of martensitic phase transformations for dissipating large strain energy. Use stress-induced phase transformation materials in passive armor.	C. Rogers

Table 1. Structure/Armor Ideas (continued)

Issue No.	Issue	Proponent
17	Develop active mounting hardware for modular concepts; i.e., shape memory alloy velcro and shape memory alloy structural and electrical connectors.	C. Rogers
18	Institute full-field qualitative sensing techniques for health monitoring using active materials/transducers.	C. Rogers
19	Develop active tagging for evaluation of thermoplastic welding and qualitative evaluation of health and structural integrity of composites and bonded joints.	C. Rogers
20	Develop active vibration control for firing accuracy—isolate terrain-induced vibrations and recoil signatures—can be accomplished by utilizing semiactive and active control on numerous subsystems.	C. Rogers
21	Develop semiactive pallets for air drops.	C. Rogers

Table 2. Signature/Sensors Ideas

Issue No.	Issue	Proponent
1*	Develop active acoustic control for low-frequency signature reduction and random scrambling. Use active disturbances for scattering or scrambling signatures for vehicles and munitions. Develop active structural acoustic control techniques to reduce low-frequency signature using existing technology at greatly reduced mass, compared to any other passive design. Need to include hybrid control approaches.	C. Rogers
2*	Investigate short barrel technologies.	O. Cathey
3a*	Develop extension of electrochromatic glass to thin film polymeric materials for active camouflage.	C. Rogers
3b	Use adaptive "bumpy" surfaces for altering observability—technology being developed for turbulent boundary layer control for the Navy.	C. Rogers
3c	Fast-growing, "Chia Dog" approach to growing foliage all over tank—reduces visual, IR signature.	B. Moore
3d	Use lighting to reduce the visible tank shadow in the desert.	D. O'Kain
3e	Similar to the effect of heat on shape memory alloys, enable light to change local hull shape to greatly reduce reflectance.	B. Moore

Table 2. Signature/Sensors Ideas (continued)

Issue No.	Issue	Proponent
4	Elastomeric bladders mounted on various areas of the vehicle that could be inflated to change RCS and IR signatures.	W. Haskell
5	Fill P900 Armor (holes) with foam and fillers to incorporate RCS and IR signature reduction.	W. Haskell
6	Use low-emissivity, high-emissivity, tough materials such as B4C and diamond for low observability.	A. Akerman
7	Consider the MMW transparency of composites for use as windows on NVEOD sensors.	L. Ogborn
8	Develop composite tracks.	O. Cathey
9	Smart materials for suspension. Electrorheological properties of polymers could be further developed to control/manage suspensions, recoil mechanisms. Use electroceramic-controlled orifices for active recoil systems or suspensions systems.	D. Granville, C. Rogers
10	Develop active noise cancellation for isolating acoustic sensors united by self noise.	C. Rogers

Table 3. Propulsion/Energy Transformation Ideas

Issue No.	Issue	Proponent
1*	Assess hybrid drive train diesel engine - generator/converter (AC/DC) - electrical motor each wheel - battery.	S. Sanders, W. Haskell
2*	Research and develop adiabatic diesel engines.	O. Cathey
3*	Replace main gun hydraulic recoil system with an electromagnetic system; a dynamic muzzle brake; an active recoil system counter jet; compressible liquid polymer springs; piezoelectric energy converters.	R. Gast, L. Puckett, K. Iyer
4	Phase change materials to absorb heat generated by exhaust gases and for passive thermal energy storage.	D. Granville
5	Motor signature analysis could be applied to all aspects of electrical uses in tank to increase efficiency.	A. Akerman
6	Develop a pivoted pod/spoked wheel for armored vehicles.	S. Sanders
7	Rapid displacement technology (Jack Rabbit).	Z. G. Sztankay

Table 3. Propulsion/Energy Transformation Ideas (continued)

Issue No.	Issue	Proponent
8	Use chaotic time series analysis and feedback to increase engine and propulsion efficiency.	A. Akerman
9	Use jet turbine tank engine to propel the tank through thrust rather than through transmission and tractive effort.	L. Puckett
10	Expand use of fuel cells.	O. Cathey
11	Make vehicle floatable.	R. Peterson

Table 4. Lethality

Issue No.	Issue	Proponent
1*	Fully exploit storage/logistics advantages of LP.	R. Eichelberger
2*	Weapons: Totally eliminate large KE weapons and replace with missile or CE and have advanced 30–50-mm AP automatic cannon for both ground vehicles and rotor craft defeat.	W. Haskell
3*	High-energy laser to detonate reactive armor.	O. Cathey
4*	Reduce gun size and retain lethality with advanced ammo or sacrifice some lethality.	D. Orphal, C. Anderson, Jr.
5	Use steam as propellant based on FCI.	A. Akerman

Table 5. Other Ideas

Issue No.	Issue	Proponent
NBC	Biosensors to activate NBC countermeasures.	O. Cathey
COMMO	60-GHz radio for communication between tanks.	O. Cathey

Table 6. Philosophical Comments

Issue No.	Issue	Proponent
1	Management of innovation.	R. J. Eichelberger C. E. Anderson, Jr. D. L. Orphal
2	Multidisciplinary optimization.	G. Farley
3	Need for combined efforts to look at optimum hull designs.	W. Haskell
4	Systematize a technology as early as possible.	J. Ploskonka
5	Design guides.	W. Haskell
6	Crew size.	W. Haskell
7	Assess tradeoff for multihit protection.	R. J. Eichelberger
8	Assess minimum weight of structure for vehicle w/o protection.	R. J. Eichelberger
9	Develop realistic evaluations of tradeoffs between stowed load requirements and time of continuous operations.	R. J. Eichelberger
10	Develop design methodology for system integration based on "where does the energy go?" and "where do you want the energy to go?"	C. Rogers
11	Two classes of tanks? An SOA 60–70 ton which will beat anything and a 20–30 ton which would be less capable but fine for regional conflicts.	D. Orphal
12	Signature teams - vehicles work in teams to evaluate effectiveness of camouflage and concealment. Each receives readiness from several different portions.	D. O'Kain
13	Energy for safety - accommodate a factor of safety by using energy instead of passive mass.	C. Rogers

2. THE WORKSHOP

The Future Technologies Workshop was held 9–11 June, 1993 at Aberdeen Proving Ground, Maryland, by the U.S. ARL in collaboration with the U.S. Army TARDEC. The objective of the workshop was to respond to a challenge to the composites community within ARL by Mr. Richard Vitali, former Acting Director, ARL, to provide guidance on what technologies ARL should be addressing for

the next fleet of armored fighting vehicles. The focus was on the structure, signatures, and armor protection of a future ground combat vehicle.

ARL and TARDEC management and researchers provided briefings on vehicle requirements and constraints the first day. Invited participants from industry, academia, and other government organizations were asked to submit brainstorming ideas via index cards during these briefings (see Appendices A and B).

A list of the ideas was printed and distributed to the participants the second morning. The submitter of each idea was then given two minutes to succinctly describe his/her idea. At this time, and later, some ideas were bundled with others, changed, or withdrawn with the light of day. We divided the ideas into the following areas: Structure/Armor, Signatures/Sensors, Propulsion/Energy Transformation, and Lethality. We then prioritized the ideas within each area to determine which ones would be discussed at the focus sessions in the afternoon. Some of the ideas were determined to be philosophical in nature, as opposed to actual vehicle notions, and comprise section 8. The focus sessions were a series of four, 45-min concurrent sessions dedicated to the top ideas in each area.

Those ideas, which were topics of the focus sessions, were briefed to everyone the third morning, usually by the proponent of the idea. A suggested format for proponent presentations had been provided (Appendix C). This session was taped and transcripts were provided by LB&B personnel at ARL. There was also a challenging presentation, "Devil's Advocate," by Dr. Wolf Elber (9). The third afternoon was an open, informal discussion on "Where Do We Go From Here?" (10).

3. STRUCTURE/ARMOR IDEAS

3.1 Advanced Material Hull.

Proponent/Presenter: Mr. William Haskell

Description: This is an advanced armored vehicle hull offering multifunctional performance. We want to build in structural capability; ballistic capability; signature management, both radar and cross-section reduction, hopefully acoustic and thermal reduction as well; and it has to be hardened against nuclear, biological, and chemical threats. Some of the material you'd hopefully use in a hull like this would be

low-cost titanium, a variety of composites, ceramics in armor applications, and a variety of radar-absorbing materials and radar-absorbing structures.

We have a variety of goals and payoffs. The primary goal is weight savings for enhanced mobility and transportability. As important as survivability, and I think it's apparent now to everyone, is that if we're going to reduce a tank from 70 tons down to 50 tons, we have to make tradeoffs. So I think our goal should be, for survivability, to have the maximum attainable survivability for a 50-ton vehicle compared to what might be available today for a 50-ton vehicle. In order to do this, we're going to have to use advanced passive and reactive armor, and also depend quite a bit on an active protection system, which you'll hear as another issue in this work area.

I think for a design goal, we need to make this hull structure as smooth and clean a surface as you can get to optimize the signature reduction. We also have to worry about the cost to produce this vehicle, and I think we have to make sure that the cost of the hull is a reasonably low percentage of the total vehicle cost in order to sell it.

These are some of the issues. I already mentioned protection level. To get down to our weight reduction we have to make threat tradeoffs. Some of those tradeoffs would be the defeat mechanisms. What can we give up is that we would normally use—reactive or passive technology—and trade it off to an active protection system. As far as the design of our hull, we were trying to determine what the threat protection would be, and we decided that the outer structural hull would have a minimum protection level against AP, frag, maybe hand-held HEAT in certain areas. It would have an embedded, highly protected crew module, which could offer some of the higher threat protection levels, and if possible, this would be as modular as possible to remove armor packages and upgrade. As for the construction method, many different options were discussed: a titanium structure, with ceramic appliques, and a composite liner; a highly loaded frame structure (frame could be titanium or some type of steel, or it could be combinations of different types of composites) with bolted-on armor panels (which I think would add to the rigidity of the frame); and then there could be some hybrid of the above, where we could have totally different upper and lower hull sections.

The organizations that would be involved—of course, primarily it would be TACOM. We'd have to work closely with Picatinny and MICOM as far as weapon development, because the weapon you design would affect the loads, and this consideration would be important early in our program; WTD for armor

and active protection system, with support from S^3I. S^3I would also help with, maybe, embedded sensors in the hull; VSD, for structure and processing expertise; and MD for materials and processing expertise. And of course, there would be other organizations involved that I didn't list. I feel the risk right now is high with the current funding obligated to the program. I think if we could get adequate funding, we would have a medium-risk program to meet our goals in the 2010, 2015 timeframe.

A plan of attack: I think, first, we have to get a development program going to prove that low-cost titanium is an option with regard to the processing, characterization for mechanical and ballistic properties, weldability, and formability. At a minimum, it's going to be a five-year, $5M effort. From my standpoint, I think we want to try to complete the ARL heavy hull program and do a field test on that, and get as much information out of that composite heavy structure. A combination of that and the titanium would be used for the design allowables for the heavy structure. We have an ongoing TACOM CAV ATD. They're completing Phase One; they're going into Phase Two. A lot of good information from this program would be transferable into an FMBT program. And of course, we have to optimize the armor development work ongoing at WTD and other government labs, trying to figure out how that armor will be integrated and the mounting provisions to put them on the hull. As I mentioned before, there has to be very close coordination with the weapons development people, the power train people, and the suspension people.

3.2. A Single, All-Purpose, Active Protection System.

Please note that there are two versions of this: (A) presented by Mr. Skaggs and (B) proposed by Dr. Eichelberger.

Proponent A: Dr. Robert J. Eichelberger

Presenter: Mr. Bob Skaggs

Description: Our group definition of active protection is that it is something that's located on the vehicle; I call it the "reach out and touch someone" technique. Here's an incoming missile; you throw something up in the way of that missile to cause the warhead to detonate, prior to its getting within lethal range of the vehicle. There are actually two kinds of systems today. There's the one that reaches out roughly 50–100 ft, maybe a little bit farther, puts up an array of something out there for the missile to run

into, and causes the warhead to detonate. There's another system in existence which will actually vectorize the incoming round, either a missile or a long rod penetrator, right at the hull of the vehicle, and cause a certain plate or plates in the reactive area of the vehicle to be detonated, and react against the incoming penetrator. The object, as I see it, is to integrate these two systems into one single all-purpose system that will address the issue of things way out there, and also address any leakers that get in very close to the hull. If you do that, then you gain something: a reduced weight from having a system that has less of the associated equipment for detection and initiation there, detection and initiation here. You combine those two, and what you do is turn a defense into a very good offense. We view it as a high risk, and long-range, and guess that it would be 15 years at the earliest where this system could be proven and integrated into one, and perhaps even 25 years. The synergism here is that you keep it simple, you actually reduce the complexity significantly by incorporating these two together, and it reduces the weight, which then gives you higher mobility. There isn't any easy way we can see to do this; the way the group discussed it was to basically develop each system separately, and at the point where both of the systems are functioning properly, integrate them into one operating system.

Questions that came up in the discussion: How robust if this system? Can it deal with such things as the marine who drives into trees, or the group of people who walk around on the exterior of the hull—are those going to cause problems with it? Will it be able to deal with a large variety of threats? Will it be able to sense and react at the proper time against a threat which is one that you want to defeat, but at the same time not react against some of the smaller threats which aren't going to do any damage to the armor which you're carrying on the vehicle. The dividing line is roughly 30–40-mm diameter for KE penetrators and probably at about a basic TOW, or there about, for the CE penetrators. One of the things that we see is that this requires a fairly long development time, so it's going to take a commitment on the part of people to support it. There are currently a couple of contractors who are doing the "reach out and touch someone" system, and they've been relatively successful. There are also a couple of contractors who are working on the system right at the hull, and that's undergoing tests; it's moderately successful at this point. And so, my suggestion here is that they continue to be supported; they have a good start on the problem, and by supporting them we will avoid duplication. The contractors ought to be followed by ARL and TARDEC because the MOA with ARPA goes away at the end of this year.

Question: Have you addressed 25-mm, 30-mm cannon AP vs. lightly armored vehicles, say, Bradley?

Skaggs: No. That is a hole in our discussion on active protection.

Proponent B: Dr. Robert J. Eichelberger

My idea was NOT to combine the two current types of APS, but to use only the flying plate type for protection against the entire spectrum of anti-armor threats. My work has not included a detailed analysis of the effectiveness of any single design against both HEAT and KE penetrators, but it has led me to believe that a design can be produced that will provide adequate protection against both. It would have the advantage of simplicity, compared with the shotgun type of defense usually proposed for anti-HEAT protection. The major question that would arise is that of multi-hit protection. That issue, like a number of "user" fetishes, needs to be subjected to a detailed, objective analysis. The "idea" offered at the workshop called for a thorough evaluation of the feasibility of a single, multi-purpose APS of the proposed type, including the negative aspects.

3.3 Composite Engine and Transmission Parts.

Proponent: Dr. Lawrence Puckett

Presenter: Mr. Dana Granville

Description: Composite engine and transmission parts are for lower temperature applications. This addresses the capability to produce composite lightweight parts, such as valve covers, transmission cases, gears, connecting rods, and other components—possibly drive train components. The payoff is lighter weight, and less corrosion, lower coefficients of friction, self-lubricity in some cases, lower vibrations (less low-frequency noise), and the ability to decouple engine noise from the drive train. Risk: We feel it's low to medium for a tech demo just to make prototypes of any given component for these types of engines. But it may be high for manufacturing; producibility may be an issue. Synergisms are better engine transmission efficiencies due to closer tolerances. You're not just machining these things to a tolerance, you're able to mold these or possibly even sinter. There's work we did in the past, back in 1976, using very fine silicon carbide powders with low molecular weight polymers, for injection molding of turbine blades, for instance. You could do that and then you get rid of the low molecular weight powders by slowly melting and sintering the ceramics of high temperature applications. There's lower coefficient friction with some of the polymer matrix composite materials, and lower inertia because there's less mass involved. Suggested investigators are MD, but also VPD, of course, with TARDEC and VSD

in structures, because we want to be able to see how, in a coordinated program, these materials would fit on an engine, and how they'd interact with existing materials in the design envelope of an existing engine.

Plan of attack: Identify specific engine types, performance requirements, and candidate transmission components. Also decide which types of materials we should investigate. Polymer matrix composites—there have been some applications already over the years. One company in particular, Polimotor, USA, has used Torlon materials, polyamide imides, marketed now by Amoco, and some of their other polyimide-type materials, with a high-carbon fiber, either whisker or short fiber, to get continuous use temperature in the range of 450° F. Companies will say it will go up to 650° F, but that may be for very short durations. Continuous use is a big issue there. Metal matrix composites—for many of them, continuous use is to 850° F, in some cases higher; ceramic matrix is over 1,000° F, sometimes over 2,000° F. Process selection optimization would be part of the program, optimizing the particular material in the process. I mentioned sintering as one example; injection molding of polymatrix composites would be another. Metal matrix composites is an issue there, getting homogeneity with the fillers that are involved in metal matrix, whether it be, say, magnesium or aluminum, and performance testing and validation with the TARDEC folks.

Issues: Homogeneous properties, getting a good homogeneous part—it's one thing to be able to take sheet stock or rod stock that's continuously produced in metal matrix, for instance, in getting good properties out of a chunk of material. But if you're going to do a forging or a casting, you might find that you'll be getting orientations you don't want. So that would become a processing issue. Distributed vs. point loading of some of these materials—some of them are notch sensitive, so that has to be taken into consideration. You're not talking about a straight one-for-one substitution of composite materials or polymer materials for an existing part. Exposure to transmission: adverse effects of hydraulic fluid was mentioned in the presentation before. Cost-effective productibility, the scale up; that's a big issue. And again, this is something that would be a dual program that everyone can participate in.

Transition Into a Future Vehicle Concept: It just has to be tailored to be compatible with an existing power and space envelope.

3.4 Graded Z Layers of Fiberglass.

Proponent/Presenter: Mr. Bob Skaggs.

Description: Initially a graded atomic number layer for absorption of x-rays starting with a low atomic number at the exterior surface of the hull and going to a fairly high atomic number in the interior surface of the hull was considered. In addition to that, there's color that can be added to these fibers for millimeter wave and radar absorption. A question was raised by Dr. Frasier: Is it possible to make these an EMP absorber? I think that's one of the things we'd like to look at, but at any rate, it addresses additional protection requirements being built into the hull for, initially, nuclear, but in addition to that, radar, microwave, EMP, energy, and even building in the camouflage. The payoff is that there's a very small weight penalty for doing this. There's just a slight increase in density when you put these absorbers in, but basically the density of the fiber is about 2.5 g/cc; that's the density of glass, and so anywhere you use the ordinary S or E glass fiber, you can use these fibers in its place with a very, very small weight penalty and very little cost increase. There will be no space requirements for this because it will be a direct replacement of the S or E glass fiber with this fiber. Normally, these fibers come about 390 fibers to a bundle or a tow, and that's exactly what the S glass is. It will work anywhere S glass or E glass materials will go. One issue is that the properties of these loaded fibers are not known. The plan of attack would be first to contact the manufacturer, obtain from him the properties, and if they didn't have the properties, then buy some materials and verify those properties yourself. Then the next step would be to fabricate structures of the like that are desirable, such as either laying up over a mandrel or vacuum bag flat plates and testing those against the various kinds of radiation to see what the results are. It's relatively straightforward, and I think a low risk is associated with this kind of approach. Both Los Alamos and Oak Ridge have been working with these for a long period of time, and, I think—you can correct me, Dr. O'Kain—but the mandrel capability that the people at Oak Ridge have is very, very large. So I think you could properly lay up an M113-size vehicle right now, down there. Using those facilities, you'd avoid reinventing the wheel, so to speak, and it would be a leap ahead in technology fairly quickly.

Question: What about attaching ceramic tiles on the outside?

Skaggs: We've looked at the possibility of molding or incorporating ceramic tiles or other kinds of material in the layup. Yes, you just lay up the material over the wet wrap, the ceramic tile. So, you embed the ceramic tile in this stuff, as opposed to attaching it to the exterior surface.

Sanders: The problem with EMP is its wavelength is so low. What you'd have to do is establish continuity at the edge of your plane, so you would get a Faraday shield. At higher frequencies, if you're absorbing, you're reflecting immediately before it hits the edge. It wouldn't work for millimeter/microwave.

Spurgeon: Your outer layers are absorbing. I need the outer 0.25 in (for signature reduction). Beyond that, I don't care what you do with the fibers—we can coat them with metal.

Skaggs: Or use a metal fiber. Actually, we've woven some of the stuff out of tantalum.

Spurgeon: My recollection about the fabrics being discussed is that they're not as good as E glass.

Haskell: The big issue is the mechanical properties of these filaments. The tensile properties are dramatically lower than S glass, like 80%. If you reduce mechanical and ballistics properties, we may lose our weight advantage.

Skaggs: On the other hand, it doesn't take very many of these fibers to do the absorption, and you can either co-bundle them in a tow or you can use them as the warp of the fill yarn. In other words, if the warp is these loaded fibers, and fill is the S glass on one ply, you may need just a few more plies than you ordinarily would've used of S glass. I called them a tailorable absorber when I was designing them.

Spurgeon: You could put increasing Z materials in your binder.

Skaggs: That could be done also, because the filaments are run through an epoxy tray before they are wound on the mandrel, and it would be easy to load the epoxy as well as the filament itself. You could actually tune for different atomic numbers that way.

Question: How about resisting NBC?

Skaggs: I guess we don't know, but I think they're going to be like a pyrex glass, and if you know what the behavior of pyrex is against those chemicals or contaminants, then you can characterize it. They're currently used in the chemical industry. The NEXEL fiber is a chemical-resistant fiber that is used for trays or continuous belts in a hot furnace.

Question: Are there any guidelines for what we really need to do about the nuclear part of this problem?

[There followed considerable discussion on codes and experiments at Oak Ridge, Los Alamos, and within the Army indicating that the techniques are available to address these issues.]

3.5 Mature and Exploit Ceramic Composites, Explosive Reactive Armor.

Proponent: Dr. Dennis Orphal

Ceramic composite armors and explosive reactive armors have individually demonstrated very significant mass efficiencies. The net mass efficiency available by combining the two is much less certain.

- Mature both of these technologies individually and in combination.

- Initiate analyses/design/fabrication studies and preliminary ballistic testing to investigate the incorporation of at least passive ceramic composite armor into a composite "hull."

Payoff: Weight reduction and/or increased survivability.

Risk: Medium.

Synergisms: Extends/matures previous research on both ceramic composites and explosive reactive armor, composite hull.

Suggested Investigator/Organization: ARL and appropriate contractors.

Plan of attack:

- Sustained research program.

- Increased/improved coordination between composite hull and armor research programs.

- Use of contractors.

Issues:

- How to combine passive ceramic composite and explosive reactive armor to achieve optimum mass effectiveness against all threats of interest.

- Improve effectiveness of passive ceramic composite armor.

- Improve effectiveness of explosive reactive armor.

- Optimize means to integrate with composite hull.

3.6 Rotating Armor.

Proponent: Dr. Donald Eccleshall

Description: The armor concept to be described consists of an array of disk flywheels rotating at high speed in front of conventional back-up armor. One half of the disks rotate in one direction and the other half in the opposite direction so that the total angular momentum is 0. The array is designed so that a penetrator incident on any armor panel would encounter at least two disks with high probability, and at least one disk would be hit at a point more than half way out from the axle to the periphery where the disk velocity is significant. When a penetrator intercepts a disk, a slot is cut in the disk and momentum is transferred laterally to the projectile, causing it to be deflected, tipped and, possibly, broken up. In consequence, the amount of passive backup armor to prevent penetration by the residual rod is relatively small, and the overall areal density of the panel comprising disks and backup armor to defeat the penetrator is reduced relative to RHA (mass effectiveness is increased). In the following, we consider the design of such armor for an Abrams class tank and estimate scaling relationships to cover quarter-scale applications. Other uses for the stored angular momentum in the disks, for example to stabilize the vehicle on the move, are mentioned.

3.6.1 Point Design Estimate to Defeat a Full-Scale KE Rod. For the purpose of this analysis, we assume a three-layer array with each layer comprising a plane of nearly contiguous disks (other arrangements may be more efficient). Individual disks in the array are taken to be made of RHA, 60 cm in diameter and 2 cm thick, and having a mass of 45.24 kg. Each disk in a layer is separated from

its neighbor by having a 2-cm space between the nearest points on their peripheries. The array comprises three layers of disks such that their axes are 31 cm apart in a square pattern. The disks are presumed to be accelerated to an angular speed of 1.33×10^3 rad/s, corresponding to a tip speed of 400 m/s which is about the state of the art for rotating machinery.[1†] At this speed, the disks have a kinetic energy of 1.81 MJ, and the total rotational energy for a three-layer array 20 m^2 in area (about the area of the side of an Abrams) is 312 MJ. It is believed the disks could be accelerated by induction, by embedding magnets in the disks, or by homopolar motor technology. Sufficient space must be provided between layers to accommodate magnets, coils, cables, or other components needed to accelerate and control the rotation of the disks, and no estimate of the weight burden from these has been made. It is believed to be insignificant, and in any event a contributor to the overall useful passive armor areal density. In order to accelerate the 156 disks on a side in a period of 10 min, an electrical generator with a power of 500 kW would have to be provided and driven off the vehicle's main engine. The weight of such a generator is estimated at 500 kg,[2] that is, about 7% of the total weight of the disks. It is presumed that the disks can rotate on essentially frictionless bearings, that windage forces are small, and, once accelerated, spin can be sustained by the 19-kW generator presently onboard, or even by the new 2-kW Auxiliary Power Unit.

Payoff: The major payoff—and the design driver—of the system is to defeat KE projectiles. Other threats, including shaped charge jets, can be defeated in much the same way as is proposed here. The armor application is treated in the next paragraph. Other applications are mentioned following it.

3.6.2 Defeat of KE Projectiles. We postulate a threat comprising a 2.54-cm-diameter rod of length 60 cm (L/D = 23.6), made from very heavy alloy (tungsten, say, with nominal density = 18,000 kg/m^3) and moving at 1.7 km/s normal to the disks. On penetrating an outer skin, such a threat would make a hole in a stationary disk of diameter 5.32 cm according to a relation due to Frank and Zook.[3]

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[1] Gulley, J. Private communication. University of Texas. Summer 1993.

[†] Mr. Gulley, Center for Electromechanics (CEM), has tested all-steel rotors up to 350 m/s and believes 400 m/s would be possible (private communication). He indicated that the major design problems stem not from the fact that the tip speed is faster than the speed of sound in air but from the difficulty of designing bearings, especially ones that will have to withstand gyroscopic forces. In this array of counter rotating disks, sound-speed effects other than "windage" may become important, of course, and we therefore may have to provide a partial vacuum, or purge with helium.

[2] Jokl, A. L. "Electric Generators: Technology Status." IEEE AES Systems Magazine, December 1991.

[3] Frank, K. Private communication. U.S. Army Research Laboratory, Aberdeen Proving Ground, MD.

Furthermore, the disk is so overmatched that a slot would be cut in a rotating disk. The slot length is approximately 12.7 cm and the total mass "displaced" from the disk is between 0.5 kg and 1.4 kg. Assuming conservatively that the fraction of the destroyed momentum that is imparted to the rod is governed by the rod dimensions, the total lateral momentum imparted to the rod over its whole length is about 240 kgm/s. This corresponds to an average lateral velocity being imparted to the rod of approximately 45 m/s, which is enough to deflect the rod laterally by 2.7 cm in a flight path of 1 m. It also corresponds to a pressure being applied to the rod by the disk of 500 MPa, or about 75 ksi. When account is taken of the fact that nonsteady conditions will exist at initial impact and the rod itself is in a state of stress owing to the initial impact with the skin, it seems plausible that rod breakup could occur with the chunks deflected by different amounts, thereby being incident at a different angle of attack on the passive backup armor or over an extended area. Even assuming that no breakup occurs, but that the mass of the disk is configured circumferentially in order to modulate the lateral velocity, the rod will present itself to twice its own cross sectional area of the backup armor. When allowance has been made for the amount of erosion occurring in a single disk and for the increase in area impacted after a drift of one penetrator length, an overall $E_m^* \sim< 2$ is estimated. Better performance might of course result if the disks were thicker, made of heavier alloy, or inclined at an angle to the incident threat direction, although in the latter case the increase would be at the expense of space effectiveness. Further refinement of these predictions will have to await computer simulation or range experimentation. Many tradeoffs are possible; for example, if the high tip speed is not practical (the state-of-the-art tip speed for commercial solid rotors is 300 m/s),[11] one could increase the density or thickness of the disks to recover some performance.

Rods with a diameter of 0.63 cm (0.25 in) would be deflected at four times the lateral velocity given before, namely, 180 m/s, and the potential for higher E_m is clearly there. One may, however, prefer to trade off increased performance in this case against a lower disk speed, thereby decreasing the stresses on the disks, bearings, and structure.

3.6.3 Vehicle Motion Stabilizing. The total angular momentum available in the disks on one side is taken to be that of half the disks, all rotating in the same direction, and equal to 2.1×10^5 kgm^2/s. This is comparable to that for a 60-ton tank rotating at 1 rad/s, or 60°/s. Thus, it would be possible to

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* E_m is the mass effectiveness factor, defined to be the areal mass of RHA divided by the areal mass of the armor considered.

[4] Scott, D. J. et al. "Development of High Power Density Pulsed AC Generators." 8th IEEE Pulse Power Conference, San Diego, CA, 1991.

compensate for the sudden terrain slope changes by actively destroying some of the disks' angular momentum. Because this represents very inefficient use of the disks' angular momentum, and because it would be impossible(?) to engineer a reversible system, one might only want to take advantage of it when actually firing on the move.

3.6.4 Turret Turning. The angular momentum associated with turning a turret and 120-mm tube at 750 mils/s is about 9.0×10^3 kgm^2/s, or about 6.6 disks worth. Thus, one could activate a turret turn by destroying the angular momentum of about 6 disks, or appropriately reduce the speed of a larger number of disks that are deployed to protect the turret from top attack. The partial speed reduction option is more efficient, and it would be difficult to devise a reversible system; one would have to destroy a comparable amount of angular momentum in the counter-rotating disks to stop the turret rotating. The technique may, however, be useful to eliminate any tendency for the vehicle to slow on its tracks as the turret rotates.

Risks: High. How do you protect hatches and antenna/sensor apertures? What is the cost and maintenance burden? How do you minimize damage to neighboring disks when one is hit? Compartmentalize disks?

Suggested Investigators/Organization: ARL-WTD in conjunction with a vehicle designer.

Plan of Attack: (1) Conduct more detailed analysis of KE defeat performance using computer code simulation and subscale range testing to optimize the defeat mechanism. Perform analysis to optimize the array parameters (the size, speed, and material of disks, and the array geometry) and (2) conduct range tests on an array.

3.7 Moveable Armor (Catcher's Mitt).

Proponent: Dr. Z. A. Sztankay

In a variant of active protection, the idea is to move a heavily armored section of an otherwise lightly armored vehicle to the predicted impact point. The analogy is to a catcher's mitt, or better, to a goalie moving his stick to block a puck. The first estimates of the predicted impact point may be available around 1 s before impact, and positioning of the "mitt" should begin then, with corrections to the path of the "mitt" as better estimates become available.

Payoff: Strong protection, lightweight.

Risk: High.

Synergisms: Utilizes sensor technologies similar to those for active protection.

Suggested Investigator/Organization: ARL/WTD should be the lead. Greg Sztankay, Bruce Wallace, and others at S^3I can work on the sensor(s).

Plan of attack: To be determined.

Issues: Is this idea within the realm of possibility? Can a large enough mass be positioned on a two-dimensional grid in the required time (~1 s)?

Transformation Into Future Vehicle Concept: If the basic idea is feasible, the transformation should be manageable.

3.8 Apply Armor Locally.

Proponent: Mr. Oliver Cathey

The tank would be made without armor or with very little armor. The outside of the tank would be designed in such a manner that armor can be attached easily (maybe empty boxes all over the outside for the armor to slip into). The tank would be transported to the theater in the "no armor" configuration. Earlier, standard ceramic armor blocks would have been shipped to allies for storage in potential theaters of conflict far ahead of any anticipated need. Ceramic blocks are cheaper than tanks, don't require maintenance, aren't needed, and can be stored easily. When the tanks arrives, the blocks are attached (or dropped in) to form the armor. This simple alternative (shown in Figure 1) would save about 18 tons in the transportation weight of an M1A1. It would require development of a transportable jack/loader that could lift the tank and insert the armor in-theater.

Addresses: Transportability.

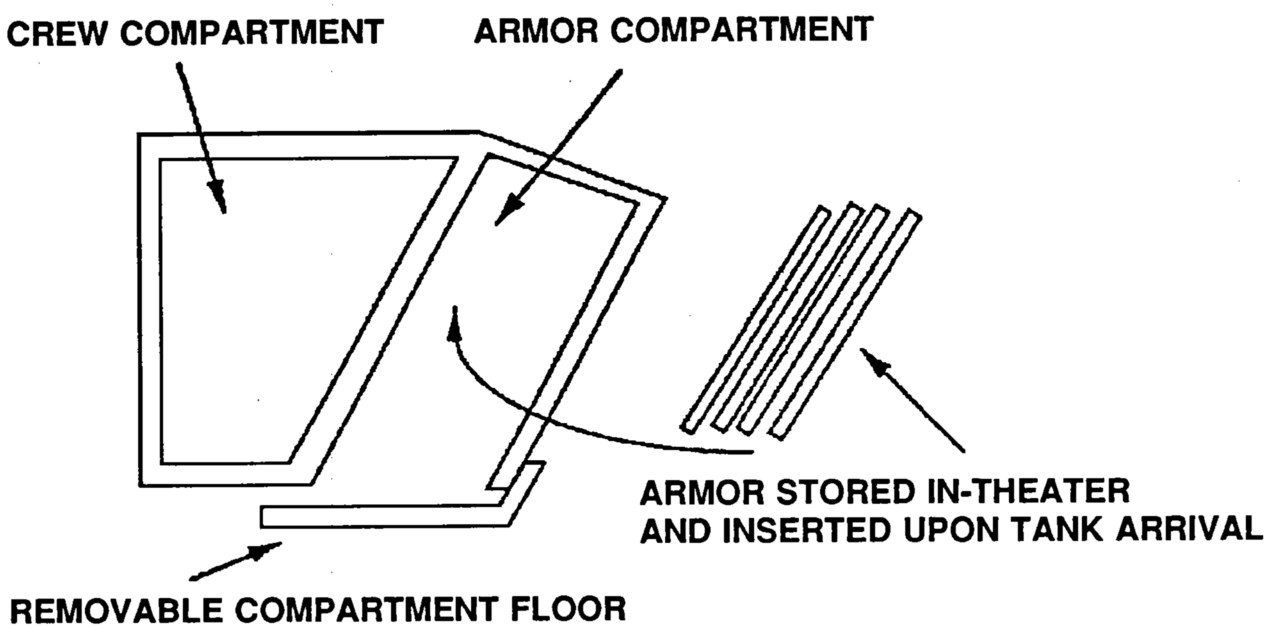


Figure 1. Armor compartment.

Payoff: A tank with no armor would weigh considerably less so many more could be transported in the same airlift.

Risk: Low.

Synergisms: Reduced fuel consumption and wear on tanks during training (and during "show of force" engagements where the enemy doesn't have heavy armor).

Suggested Investigator/Organization: TACOM.

Plan of Attack: Start with primary alternative: design and build transportable jack/loader; modify an M1A1 and test; if it works, retrofit other tanks.

Issues: How fast can you "suit-up" in-theater?

3.9 Manufacture Ceramic Armor Locally.

Proponent: Ms. Barbara Moore

Payoff: Weight savings, possibly volume savings as well, depending on mounting techniques. Vehicle can be transported without heavy armor; armor is mounted infield. Could also supply replacement tiles in the field. Armor should be much cheaper.

Risk: High.

Synergisms: Passive protection without accompanying transportation burden.

Suggested Investigator/Organization: ARL/WTD, MD.

Plan of Attack: As a follow-on to research in the SHS explosive compaction method, WTD should explore combining, say, titanium and carbon powders with sand or powdered dirt and then ballistically test the result against a pure titanium/carbon product.

Issue:

- Are there materials which, when combined with sand, rock, or dirt, and subjected to techniques—hot firing or SHS explosive compaction, can produce viable ceramics?

- Can the techniques be made portable, easy, and quick to use?

- Mounting techniques would also be critical to success.

Transformation Into Future Vehicle Concept: This should not be a problem given that the mountings were well executed.

3.10 Multifunctional Composite Energy Storage Cells.

Proponent: Mr. Dana Granville.

Addresses: Capability to design and fabricate a modular energy storage cell that can double as armor.

Payoff: Alternative to diesel engine as an electrical power source (silent, no thermal signature, could be tailored to provide desired dielectric properties); if applied as power pack modules to outside of vehicle, may contribute to defeat ballistic threats as passive or active armor.

Risk: High.

Synergisms: Combines advantages of structural/ballistic/dielectric/energy storage materials.

Suggested Investigator/Organization: ARL-MD, -EPSD, -ACISD, -WTD, -VPD, TARDEC, National Battery Consortium.

Plan of Attack: (FY94–96)

- Identify candidate materials for high-energy density storage.
- Develop energy storage and performance criteria for modular power packs.
- Determine relative effectiveness of power packs as passive/reactive armor.
- Develop design boundaries for IR, MMW signature management and control.
- Develop a model for material/structural/ballistic/energy storage/signature management design.
- Determine design criteria (size, shape, complexity, how many, mounting provisions) based on parametric models.

Issues: Energy storage/weight/ballistic efficiencies (weight is driver).

Transformation Into Future Vehicle Concept: Determined by decision to use energy storage for auxiliary power/electric drive applications.

3.11 Integrate Fibers Into Armor for Sensing, Mounting.

Proponent: Dr. Al Akerman

Optical fibers have been embedded into ceramics processed by CVI. Fibers such as glass-on-glass, gradient index, and sapphire have been embedded without losing their light-transmitting capability. The advantage of using embedded fibers is that the outer shell of the tank can be continually monitored to learn such things as:

- Is the armor properly mounted on the tank?
- Has there been a hit?
- How many hits?
- How much shielding is lost?
- From what direction did the hits come?

Such fibers could be embedded, without giving up other improved features such as low observable coatings (see Figure 2).

Payoff: Built-in means of telling what condition the tank is in from minute to minute during battle and preparing for battle.

Risk: Low.

Smart Armor:
Fiber-Optics-Embedded Ceramics

Hit Assessment Concept

* What and how big was incident shell?

* From which direction did it come?

* How many and what kind of hits?

* Low power consumption

* Continual status monitoring capability

Status

* Demonstrated fiber embedment in ceramics processed by chemical vapor infiltration (CVI)

* Fiber types:
  — Glass-on-glass
  — Gradient index
  — Sapphire

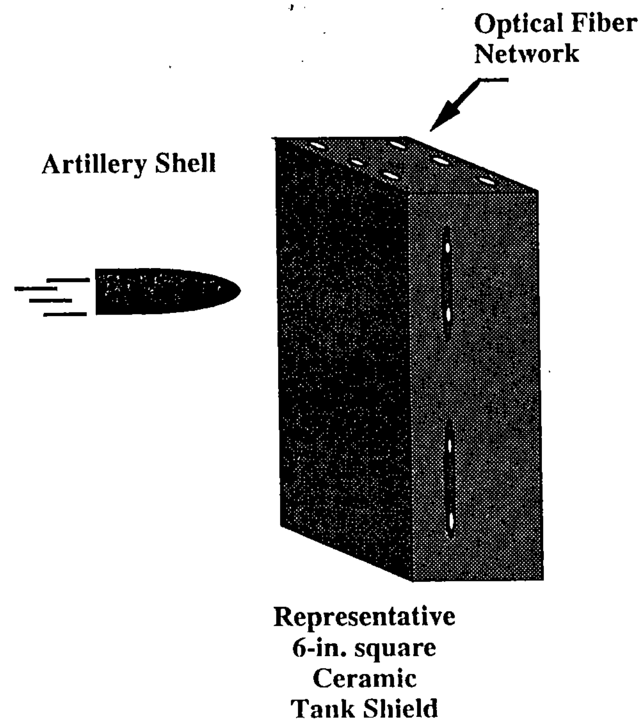


Figure 2. Smart armor: fiber-optics-embedded ceramics.

Synergisms: Fibers might be used to increase the multihit capabilities of ceramic armor at the same time that a few are used as indicated above.

Suggested Investigator/Organization: ARL/WTD, Oak Ridge National Laboratory.

Plan of Attack:

- Develop a simple, robust, modular connector to interface with armor tiles and a read-out panel within the tank.

- Demonstrate a ceramic tile with embedded fibers and interface connectors.

3.12 Develop Vehicles to Fit Into Standard Ship Containers.

Proponent: Dr. Lawrence Puckett

Payoff:

- Facilitates more rapid overseas deployment.

- Potential for lethality flexibility via modular armament pods.

Risk: Medium.

Synergisms: Would mesh with the Army's Strategic Mobility Program which requires +30 days deployment of three heavy divisions (two by ship, one by air) to overseas theaters.

Suggested Investigators/Organizations: ARL (AAVT), HRED (modular vehicle concepts), MTMC (logistics analysis).

Plan of Attack: ARL, under the AAVT, is drafting a SOW for a logistics study in conjunction with HRED and the MTMC to assess the advantages of deployment of modular vehicles. Included will be the

assessment of the potential for more dense packing of containerized armored vehicles on ships. Also of interest is the speed/efficiency of loading and unloading containers dockside.

Issues: Standard containers are only 8 ft wide × 8.5 ft high and 20 ft (most) or 40 ft (some) long. This limits the armored vehicle to a width that can be packed into an 8-ft container. If the assembled width of the vehicles needs to be greater, some sort of design such as an attached sponson would be necessary. The weight of each container (plus contents) is limited to 45 tons, due to restrictions of standard port cranes.

Transformation Into Future Vehicle Concept: Requires swift and simple attachment of the individual modules, probably an independent auxiliary power supply to enable positioning of the modules for attachment (particularly critical for air-drop), provision for mechanical, electrical, and possibly hydraulic lines, redesign of wheels/tracks to accommodate linked and independent modules.

4. SIGNATURES/SENSORS IDEAS

4.1 Acoustic Control.

Proponent/Presenter: Dr. Craig Rogers.

This includes the design of low acoustic signature vehicles using many different techniques, and actually we not only looked at trying to create a low-acoustic signature, but we also considered the ability of using acoustic signatures for deception as well.

4.1.1 Design of Acoustically Complex Structures. The basic idea is to make sure that we look at designing the structure from beginning to end, with the premise that we are going to try to create the lowest acoustic signature with the lowest amount of mass and energy required to perform the operation. So, the first thing to do is to be able to look at how to design acoustically complex structures from a passive point of view. That's very difficult to do when you're interested in low-frequency vibrations. Low frequency, being a forced vibration, regardless of the complexity of the structure where stiffness is related to compliance on the structure, still gives you a lot of these typical high-frequency acoustic radiating features, like big breathing modes of side panels, and issues of that sort.

4.1.2 Application of Passive Acoustic Treatments. The next approach you look at toward creating low-acoustic signatures is the use of passive acoustic treatments that always require mass. Passive systems work very well for high frequencies and of course, the lower the frequency, the more tonnage in lead is required. And so, as soon as you look, beginning at low-frequency (and depending upon the structures, that definition can change, say 200 Hz or below), these techniques, passive treatments, normally are fairly ineffective.

4.1.3 Active Vibration Control and Isolation. This is one approach that's oftentimes confused with actually doing acoustic control; still an important technology area to consider toward the overall system integration for low-acoustic signatures. The basic idea here is, if you stop the structure from vibrating, it's not going to radiate any noise, and that's certainly true. But this is a brute force approach to the problem. The physics of structural acoustic radiation are such that not all vibrations radiate sound or at least don't radiate sound well. A very simple example is that if you just have a simply supported plate, the first fundamental mode, the big breathing mode, is a very efficient radiator. However, the 2/1 mode, where two halves of the plate are vibrating 180° out of phase, really doesn't radiate much energy. The energy is sloshing back and forth between the two halves, and doesn't produce much sound. So when we start looking at how to perform acoustic control, the real fundamental issues are where is the energy in the structure, and where do we want the energy to go? What that means is that there are lots of different approaches to doing acoustic control. One is, if I have all of these vibrations, say this fundamental breathing mode, and this 2/1 mode, I don't want to put any energy into trying to control the 2/1 mode. It doesn't make any sound; I'll let it vibrate, but I'll put all my energy into trying to control that first breathing mode.

When you do experiments, one of the paradoxes you find oftentimes is that when you reduce the acoustic radiation signature, and when you measure the vibrational response, the overall vibration goes up, and the sound goes down. Because what you end up doing is moving energy out of the modes that radiate sound, and you've just moved it into modes that don't radiate sound. So, the real premise is how to be able to do this type of vibration control and isolation, to be able to reduce the amount of energy that's going to be required. Now, the other thing that's important here, however, is when you have known sources of the vibration or the radiating acoustic energy, trying to do the best you can with being able to isolate this energy as well. Obviously, the closer to the source you can get, the more effective your control is going to be, and in general, the less mass and energy that's going to be required in order to effect the control. The problem with acoustics is that the energy takes on different forms, and it pops up

in different places within the structure. Some of it's easy to control and others are not. For instance, you can have a vibrational source that puts energy into a structure initially that won't radiate any sound, say into an extensional vibration in a structure. It won't make any sound, but as soon as it hits a discontinuity in impedance, like a rib, or stiffener, or an end panel, then, all of a sudden, it gets transferred into transverse motion and will radiate sound. So trying to find all the load path is sometimes difficult.

4.1.4 Active Noise Cancellation. This is where, by using sound that's 180° out of phase with the disturbance that you want to silence, you basically don't perform cancellation, by actually adding energy; but the phase is important and ends up reducing the signature locally. All right, you can't perform that farfield, unless you have almost an infinite number of speakers that are associated with the specific sources that you have. It works very well for enclosed areas, and is a technology that's well developed, and in fact is being used in Boeing 747s for the crew sleeping quarters, which are in the forward part of the aircraft and are incredibly noisy. So all they do is make is a silent area around their heads where they're lying down. The rest of the cabin is incredibly noisy; you could never fall asleep in there, but as long as they're lying down in that head region, it's very quiet. So, that can work in enclosed areas relatively well, and is a very low-mass type of system.

4.1.5 Acoustic Deception. If you're doing queuing based upon acoustic signatures, we can actually alter those. We can change directivity patterns of systems. We can also manipulate the acoustic signature as well—in essence, trying to make you sound like you're moving when you're not, going someplace that you're not, issues of that sort.

4.1.6 Active Structural Acoustic Control (ASAC). This is what's going to solve problems dealing with farfield radiation problems. If the structure is the cause of the acoustics, then what you do is find those modes that radiate sound, and you control only those, either by stopping them, or by moving the energy elsewhere, changing its form. The areas that this addresses are really everything from the physical design of the hull structure to the drive mechanisms. The important thing is to be able to look at, basically, the static structure, which obviously is not static if you're interested in the acoustic signature, and be able to enhance or impact the design from the very beginning.

ASAC can, but need not be, a retrofitable solution. However, retrofits are never optimized. They're going to require increased mass. So your best way of reducing mass, with this issue in mind, is to be able to incorporate the acoustic design in the beginning. The nice thing about this, however, is that it really

doesn't change anything structurally to a large degree. It may change where you place a rib to some degree, or change impedances at the corners, or something of that sort, but has relatively little impact on any structural issues.

The objective should be to synergistically apply the above techniques to yield the lowest weight systems with the best performance. This means that the "static" or "passive" design of the vehicle must be incorporated with the design of the active control system to ensure that the energy expended by the active control system is minimized and its weight and volume reduced. In general, ASAC is the most robust approach for minimizing the farfield acoustic radiation/signature. One of the areas that was identified as being important was, in fact, just the noise caused by ground slapping of tracks, and so the design of the tracks in the drive system as well would be very important. This also brought up some issues about the sensing of acoustic signatures as well, from within a moving vehicle or one that is stopped—using ground acoustic sensors in being able to determine signatures of opposing vehicles as well as their location and orientation.

One of the other important areas is the development of active material transducers, and then the development of appropriate hybrid control systems. The physics are well known; the technology needs to be made more robust for your particular applications. A lot of this technology is being incorporated into commercial applications, particularly for control of turbo prop aircraft, and for some industrial environment applications as well. The payoffs are reduced detection range, and that can either be from human ear or acoustic sensors, and those acoustic sensors could be either airborne or ground sensors. The risks I would assess at being around medium to low. The physics have been well investigated or are known. I think the issue is one of the physical design. The transducers must be designed and evaluated for the infield robustness that's going to be required. All the active materials (and I know that there are some other issues that will come up this morning, dealing with various active, smart materials type solutions) are highly nonlinear, every single one, without exception, and none of them has truly been characterized and investigated for reliability and life expectancy, particularly for these applications that everyone's now investigating. I mean, that is across the board.

Synergisms: Even though active structural acoustic control can be a retrofit solution, its efficiency and mass would be greatly enhanced by coupling the active control design with the passive design of the treatments and structure. Likewise, the acoustic signature is also influenced by the suspension and isolation systems; therefore, interaction with the design of these systems would be beneficial.

There is some synergy here with efforts at NIST on reliability, particularly of electroceramics. The organizations that would be involved: material evaluations and reliability - MD; a number of different types of sensors, acoustic vibrational that could be embedded in the structure that could be looking farfield - S^3I; and then the structural design aspects - VSD; integration - TARDEC. Our hope would be to influence the structural design with regard to the acoustic issues through TARDEC.

The plan of attack (and some of this, actually, I'm sure, has already been done) is really to be able to map the acoustic radiation from current vehicles to determine not only where hot spots are in general in the structure, but also to be able to determine where the sources are as well. Which means determining the acoustic load paths within the structure, as well. Demonstrate the concept on existing structures. Being that it is a retrofitable solution, you can demonstrate the concept on existing vehicles. Develop robust transducers and sensors, and then integrate the acoustic design with the structural design.

The issues to be resolved really are pretty fundamental: Where is the energy in the system and where is it going, and that's really important. Where are all the sources? How does all the energy actually end up at all these hot spots to radiate sound? And then, more fundamentally even, is where do you want the energy to go? And I think this is something that is able to be used in a lot of these other issues too, particularly related to the smart material solutions, or for being able to do vibration isolation, or recoil design as well; and then of course, fundamentally, the reliability of the actuators and sensors, and then also the robustness, just for the infield, and serviceability as well.

Transformation Into Future Vehicle Concept: Active structural acoustic control will require much less weight than a passive treatment to achieve the same signature level. Power should be <1 W. Several new sensors and actuators will be included.

Question: How much of this was done for current tanks?

Skaggs: The Germans are working on something like this; they built two vehicles. One of them was basically an acoustically decoupled vehicle, the other one was not. I had occasion to ride in both of them last year. Two things: There's about a 30-dB decrease in the noise that emanates from the acoustically decoupled vehicle; and, you can actually talk inside the vehicle that has been toned down, because the level of noise inside is so much less. The net result is that the fatigue of the people who are driving or

riding inside that vehicle is going to be significantly less; they should be better soldiers when they hop out and hit the ground.

Rogers: We actually discussed the idea, the premise of trying to be able to quiet the interior which was somewhat outside the purview of our charge here. However, if you were to look at retrofitable solutions for existing vehicles, solving that interior noise problem is relatively straightforward, I mean, with existing technology. You're probably not going to get 30 dB, but 30 dB is a good number to be headed for as soon as you start talking about active structural acoustic control. Now 30 dB, for those who don't know what 30 dB is like—you go home, you plug in your vacuum cleaner, and when you unplug it, you've got 30 dB. I mean, it's a big deal, it's a whole lot.

Cathey: One other comment about the advantages of this, particularly with respect to the deception element: the mines that are currently being built and put in the field have acoustic sensors; they listen for the vehicles to go by, and they identify armor by the spectral signature; if you're moving and even if you can't silence yourself, if you can corrupt that signature, these mines won't recognize you as armor, and won't shoot you. So, there's some big advantages to doing that.

Question: Do you have acoustical computational techniques to which one can subject a design?

Rogers: Yes, actually in about the past 5 years, there are a number of fully coupled acoustic codes. The most popular commercial one is called "SYSNOISE." Most of them are finite element, finite boundary element methods for dealing with farfield radiation problems. Solving these problems in air—remember there is a whole body of knowledge out there dealing with these problems in water, a lot of effort in water. The air problems are much easier, actually, because you don't have such great coupling as you do with water. There are commercial codes that are already available to be able to do that. The national labs actually spend a lot of effort dealing with the Navy problems too, so Sandia is one that has a lot of computational capabilities in the structural acoustic problem.

Comment: When the tanks go into battle with ground troops, you want that noise there, because there is nothing as scary as seeing a 60- or 70-ton tank coming at you with all that noise.

Comment: There's nothing as scary as having an electric vehicle come up upon you when you cross the street, too.

4.2 Short Barrel Technologies.

Proponent/Presenter: Mr. Oliver Cathey

We're talking about guns, and making small guns, to the signature people. I don't care what the diameter of the bore is, I want a short barrel. This is why we want a short barrel, and why this is particularly attractive. Right now, the battlefield sensors, particularly the long range battlefield sensors, discriminate between trucks and low-value vehicle targets, and high-value armor by observing barrels on them. So it turns out that the barrel is a primary discriminant. There are a number of advantages in making the barrel short. You no longer look like armor, so you don't bring threats down upon you. You can shroud a short barrel. And the reason that the short barrel is so good is I can bury it in the top of the vehicle. In order to get a reasonably long one, we usually have to put the turret at the back, which would favor an LP type, very small breech where you could usually have the pump liquids and stuff. But you can put a shroud around this barrel; I'm showing a diamond-shaped shroud that will bury into the top of the vehicle so it doesn't look like a barrel at all. The shroud itself allows us to reduce the IR signature, through active cooling, and it also reduces the RF signature, which greatly increases our survivability.

The risk issue is obviously, if we shorten the barrel, how do we maintain the lethality of the system. That would imply higher pressures inside the barrel and a number of other things. The synergism is some reduced inertia of the turret; you don't have this huge barrel out there to give some difficulty. I also understand that we might have reduced thermal warp, which is a problem with aiming, and certainly reduced vibration with short barrels.

The length of the barrel has to be shortened to where it will fit on top of the vehicle. So you may want to make a longer, skinnier vehicle, for example, in order to get a longer barrel. And there are so many tradeoffs on that, that the primary investigator should probably be TACOM itself. Benet Lab and MD will be important.

There are a number of gun issues: a loader, or a rear-mounted turret, would be much different, whether we have liquid propellant or not, which is, I think, a big payoff with this particular type of system. So, the gun design is important. Because it is a signature issue, MD will be an important player in this, particularly for the shroud [considerable research in gun shrouds has been done at WTD in recent years].

The plan of attack: I believe you ought to study the prototype, and my guess is since so many battlefield sensors are airborne, we might want a joint service demonstration that could bring the Air Force sensors in to take a look at this.

Granville: Look at composite sabots for small-caliber sabot weapons, 25-mm or 30-mm rounds, and just due to the much smaller mass involved with the projectiles, exit velocities are obtained before you reach the end of the tube. So, you can go to lower-cost propellants. So, that allows you to go to the shorter barrel, and that may be an indicator to show that maybe, if you can go to 105 mm, 120 mm, and larger, you can go to these shorter gun tubes for a given propellant.

Cathey: What you're saying is that the composite sabot may be one solution to these issues that allow you to go to short barrel. There's a big payoff for short barrel, but short barrel means the gun doesn't stick off the end of the vehicle; that's the important issue here.

4.3 Active Camouflage System.

Proponents: Dr. Craig Rogers, Ms. Barbara Moore, and Dr. David O'Kain

Presenter: Dr. Al Akerman

The idea here (see Table 2) is an active camouflage system (3a), adaptive bumpy surfaces (3b), fast-growing "Chia Dog" (3c); lighting to reduce shadow (3d); something akin to shape memory alloys to change shapes to greatly reduce reflectance (3e). (Ideas 3a–e and 4 are potential components in an active camouflage system. Only Idea 3a is discussed in detail here. Idea 4 follows.)

So what we have is an incremental approach possibility here. First of all, there's a picture of a rug (Figure 3), so imagine a piece of indoor-outdoor carpet with the fibers facing this way, the little dot for a fiber sticking out, the finer the better. Carpets have been tested for light scatter and they tend to be lambertian–uniform light scattering in all directions, no glints. So that's a nice feature; there'd automatically be rounded edges if you put this stuff all over a whole tank. Or, short of the carpet, you could spray teflon over the whole tank. So, that would provide some radar protection or IR protection.

RUG CAMO SYSTEM

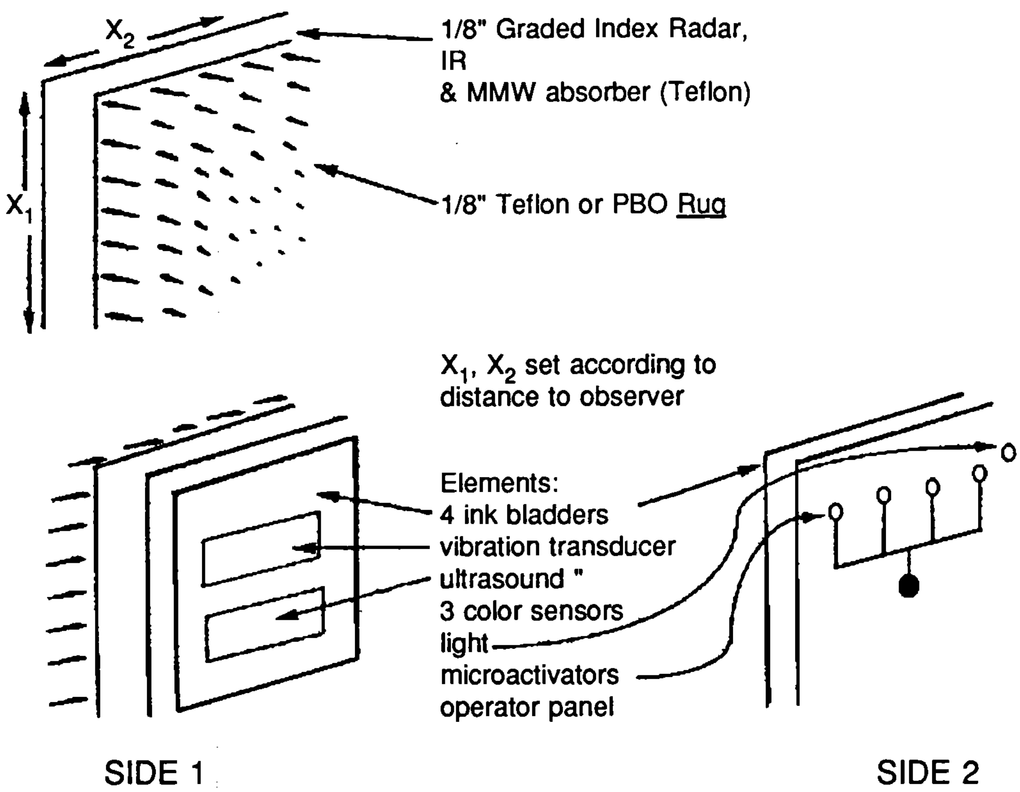


Figure 3. Active camouflage system.

Then you go another phase and you use the carpet and behind the carpet there's this eighth-inch layer that provides graded index radar, IR, and millimeter wave absorption. You have those fibers sticking out to give you the scatter and absorption properties in the visible. Adjust X1 and X2 according to the distance to the observer, so, if you're talking about battlefield conditions, you could think of these things as being 1-ft carpet squares that you attach all over the tank.

Now look down here at the lower half of Figure 3 for a more complicated system. Since there are active sensors on these, you have the problem of running wires, but I think there's a good way to take care of all those wires. We've got one half of one of these carpet squares over here (side 1) and the other side over there (side 2). So here are the carpets facing out this way and you have, say, little circles here that actually are different things. Three of them would be microactuators that would allow ink to flow from reservoirs from the back of the tile out through these microactuators and mix as they're coming out so you can have any color of the rainbow. Another one of these dots represents color sensors. So you have these sensors with filters on them so that you'd know exactly how much of any particular color this sensor was seeing.

Now then, on the back of each of these, in addition to these ink bladders, you would have a vibration transducer, so you could actually use vibration in the tank to get very low power levels that you'd need to run these tiles so you don't have to use power, you don't have to have wires coming from anywhere to drive them. And then you could use ultrasound transducers on the back as well. These would be very small. They would initiate signals and also receive signals. For instance, you could pick 50 kHz of an audio frequency wave of the human audible range, and you could have 50,100 Hz correspond to the green, 50,200 Hz correspond to the red; so you could have sensors over here on this side figuring out what color this particular tile is seeing out there, and over on this side a tile that's tuned to the same frequency that that one's transmitting, so this one turns exactly the color that one's seeing and vice versa. So any particular side of the tank or front or back would exactly duplicate whatever was on the other side of the tank, nearfield, farfield, whatever. There'd be an operator panel so the operator could sit there and see what people at a distance were seeing. So, what we end up with is a self-powered color sensor, a modular active camouflage system. It could be done with present technology, or, as long as you're stuck with the modular business and the idea of incremental improvements, you could go from a totally passive carpet square that you could put on there to get passive protection, to something a little more active like as I described. And then eventually, maybe, you could get to some of these super space-age materials, that, at present, we don't see how you could use because of problems with electrodetachment or glassy surfaces that wouldn't last very long and that make some of the higher tech things not usable. Suggested investigator: ARL. The risk is probably medium to low. The payoff, well that's your call. You could start off by designing or building two squares for, say, $50 or $100.

4.4 Elastomeric Bladders.

Proponent: Mr. William Haskell

Elastomeric bladders mounted on various surfaces of the armored vehicle that could be inflated to change the RCS and IR signature of the vehicle.

Metallic surfaces and sharp corners of an armored vehicle could add to the RCS signature. The concept is to bond a durable elastomeric bladder, in selected areas, directly onto the vehicle hull or turret. The bladder should be thick enough to be walked on when deflated and take sharp object impacts without puncture. Small air lines would be connected to each bladder to allow compressed air to be pumped into the bladder. A bladder covering a sharp corner could quickly be inflated, altering the radar return. (These

bladders strategically placed on areas of high return might be used to significantly alter the armored vehicle's RCS signature.) Usually vehicles have some type of source of compressed air in the power train. If not, a simple electric compressor could be adapted that has very low power requirements.

Payoff: Depending on the possibility of controlling the temperature of compressed air used to inflate the bladder, the IR signature could possibly be reduced. This would be a temporary reduction until the air was heated by contact with the hot hull surface, but could provide some IR signature reduction. If the bladder had an air bleed-off valve, incoming cooler air could displace the outgoing hot air, keeping the IR signature more in line with natural background temperatures.

4.5 Fill P900 Armor Holes With Foam.

Proponent: Mr. William Haskell

P900 or expanded metal armor has been proven to be very efficient in the defeat of light KE threats such as the 12.7-mm AP and 14.5-mm AP rounds. These systems can be used in place of spaced steel plate systems and work in combination with the armored vehicle hull or turret structure. The holes or slots work to tip or shatter the incoming AP core, allowing the backplate or hull to stop the resulting core fragments. The backplate material can be either metallic or composite.

Payoff: Field testing of armored skirts fabricated from this type of system showed that dirt and mud tended to get caught in, and extrude through, the hole with materials that give the outer spaced armor a smoother surface and multifunctional performance. A cast-in-place-foam-type system could easily accomplish this objective. The foam could be modified with fillers or short fibers that give it radar-absorbing characteristics by reducing reflection.

The road wheels, idler wheels, suspension components, and track of an armored vehicle build considerable heat during operation. This presents an easily detectable IR signature that can be homed in on by threats having IR sensors. The characteristics of a foam system make it a good insulating material. By optimizing the modified foam to enhance its insulative properties, the spaced skirt armor could mask out some of the IR signature by the track and suspension system heat buildup.

4.6 Low-Emissivity, High-Emissivity Materials.

Proponent: Dr. Al Akerman

Use of low-emissivity, high-emissivity, tough materials such as boron carbide and diamond for low observability. Diamond can be deposited at fairly low temperatures.

Boron carbide coating has high emissivity and is very tough due to the small interlocking crystalline features. Samples have survived in low earth orbit and in underground test without change of optical properties.

Several methods for depositing diamond on other materials have been demonstrated. In particular, the lower the temperature at which diamond can be formed, the more substrates become suitable for deposition. Diamond is an example of a low-emissivity material.

Use of these materials and others in films on armor may allow very robust, low observable systems. Of particular use would be multiple layers that provide visible, infrared, MMW, and radar low observability (see Figure 4).

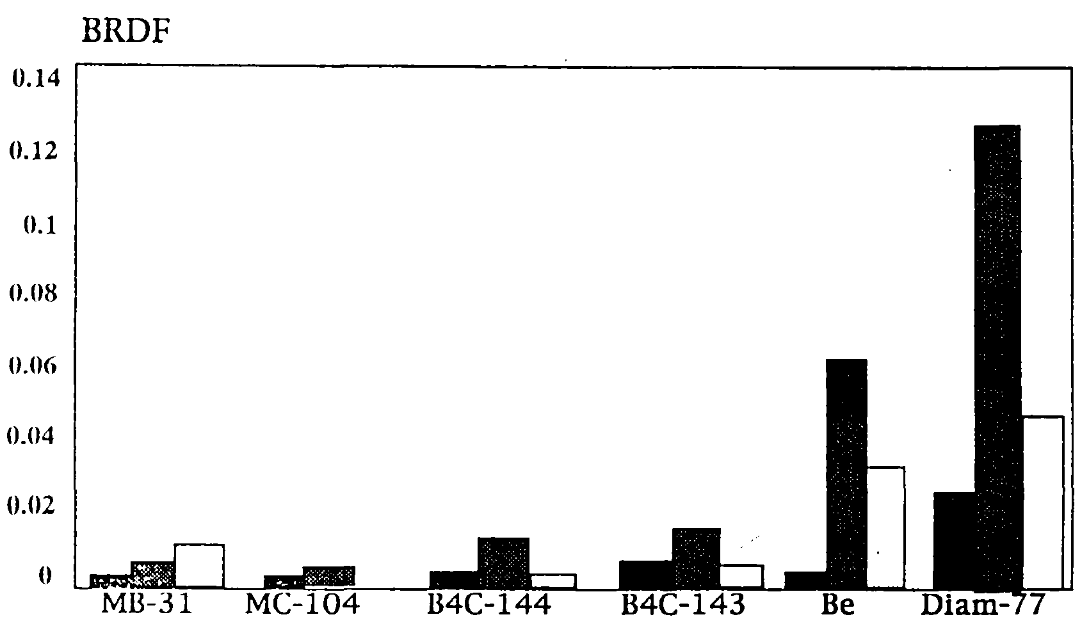


Figure 4. Broad band performance of various baffle materials.

Payoff: These materials may provide low observability while maintaining the strength-to-weight ratio of the tank armor.

Risk: Low.

Synergisms: These materials would blend the armor and low observability functions.

Suggested Investigator/Organization: ARL/WTD, Oak Ridge National Laboratory.

Plan of attack:

- Deposit representative coatings on armor, both RHA and selected ceramics.
- Measure the combined optical properties.

4.7 MMW Transparency of Composites for Use as Sensor Windows.

Proponent: LTC Leonard Ogborn

Consider using the new, lightweight, armor materials to protect the apertures of sensors. Locate and test all available armors for transparency to relevant frequencies. Inform the armor manufacturers of the need for materials that are transparent at specific frequencies.

Payoff: Such protective covers could shield the fragile sensors from small arms and small fragmentation damage.

Risk: Low.

Suggested Investigator/Organization: CECOM - NVEOD has the ability to test candidate materials for the necessary transparency. Point of contact: Jim Miles at (703) 704-1291.

Plan of attack:

- TARDEC and ARPA are developing the candidate lightweight armors. Points of contact are Dr. Jim Thompson (313) 574-5780 and LTC Bob Kocher (703) 696-2330, respectively. These people provide material samples from their contracts to NVEOD for testing.

- Application is the forthcoming NVEOD sensors.

- The mentioned parties concur with the plan.

4.8 Composite Tracks.

Proponent: Mr. Oliver Cathey

Build a track for a tank from Kevlar-Epoxy or S-glass or some other dielectric composite material.

Payoff: The track on a tank is the largest single contributor to the radar and acoustic signature of the vehicle. A composite track design would greatly reduce both RCS and road noise.

Risk: Medium. Track construction would not be difficult, but it might be expensive relative to the improvements in signature which would result.

Synergisms: Will probably reduce weight as well as signature.

Suggested Investigator/Organization: ARL/MD.

Plan of attack: Design study; prototype; road test. Try on a Bradley first.

Issue: Toughness of composite materials for this application and method of construction.

5. PROPULSION/ENERGY TRANSFORMATION IDEAS

5.1 Hybrid Power Train.

Proponent: Dr. Steve Sanders and Mr. William Haskell

Presenter: Dr. Steve Sanders

The purpose is to provide a power train that consists of electric delivery, from a turbine to the wheels or tracks, and also to provide that same power augmented from batteries. Right now, TACOM does have a 30-ton tank which used to be full turbine, which went through a transmission differential to the two sprocket drives. Of interest, but not in the drive train, is the heat exchanger, a massive bulk and weight problem, and its support systems.

They are now working with a prototype electric drive train that uses the same turbine, goes through a generator, goes through a conversion system, and drives the two sprockets. They have found that they cannot reduce the size of the turbine because they would lose their peak performance. The advantage of the hybrid system is that you would trade off the weight savings in your turbine and your heat exchanger, with weight acquired in your battery system to provide peak power. If you have batteries now as opposed to providing the extra peak power delivery, we don't know what kind of savings it would have, but we suspect it wouldn't be very much. There is an opportunity, at least Detroit thinks so, to save a lot of weight in the batteries in the future. Any energy storage density breakthrough would allow you to make a substantial reduction in the horsepower of your turbine, and its auxiliaries, which is where the real weight savings occurs, particularly that heat exchanger. That would allow you to run silent, turn the engine off, run off the battery; maybe for 1 min, 2 min, or run normal for your conventional delivery, 750 hp; or run at twice that with both disks in the battery; and to hits surges; so, your motors would have to be rated total for about twice that. If you drove four times the power, climbing a hill through the woods, or some great demand, you could do that too, for a limited time. How long could you do this to excess? It depends on how much you overload your motors; also it depends on the amount of batteries you carry, and there is a weight penalty in your energy storage.

The advantages—whether you use a track or wheels, whether or not you get this reduction—you have certain advantages in that you can get either major or minor savings in the size and the weight. You should definitely get better mileage because you are loading your turbine more consistently, not absolutely consistently, and you would be recovering energy as you brake or go downhill. This better mileage could translate into better range, or, if you end up in a tactical situation where your fuel supply is deployed, you could get more use of your fuel, and that would give you deployment flexibility. You would reduce your IR signature because your heat exchanger would be working at a more constant level, not peaks and valleys. The performance enhancements are in acceleration and range. Other advantages: You would be able to flexibly alter those performances in the tactical situation by your signal conditioning of your electronics. It would be more reliable, and because it's modular, it would be more maintainable. I think I have already discussed the issues, the risks.

You need a much better energy storage density device than we have to realize these savings. You would require some technical breakthroughs on that. You need a better signal conditioning train—the silicon devices that control the frequency, the phase, and the amplitude of your power to your wheels; and, because you have more components, even though the components are very reliable, you would probably have a greater cost.

The plan of attack: TACOM would have to provide the range of specifications that we would be researching in the performance of the materials, those materials being the energy storage device, the energy conditioning devices. And it's already a mature technology for electric motors that would go on the wheels, and it would be pretty much the same turbine heat exchanger. After TACOM defines the range of specs, we would research the components in an effort to achieve those specs, exceed those specs, or do the best we can in the direction of those specs. At which time, we would take that technology back to TACOM, they would engineer it into a system, perform the tradeoffs, and optimize it for a prototype prior to production.

5.2 Adiabatic Engines.

Proponent: Mr. Oliver Cathey

Presenter: Ms. Jennifer Hitchcock

We decided to call it the insulated engine since nobody agreed on the title "adiabatic." The engine will give you a lot of payoff in terms of your parameters, such as high efficiency and less fuel consumption, but the major payoff of this engine is lower vehicle weight. By eliminating the cooling system, you can reduce the entire system weight. Another payoff I just thought of is by eliminating your cooling system, you'll be able to get better mobility. By this I mean all your horsepower that's used for your cooling system can go directly to your sprockets. Your lower thermal signature can be achieved if you can somehow develop a better way to recoup the exhaust gases and reduce that temperature. This is not a new idea; TACOM has been working on it for quite some time. We tested a lot of ceramic coating materials for cylinder heads, and we've also tested complete ceramic components such as valve guides and faceplates. The real research needs to be done in the materials. They need to be able to take high temperature, a lot of fatigue cycling, they need to be fabricated, and of course, affordability is always an issue. Uniform burning is another issue which isn't unique to this engine, but also applies to other diesel engines. We think the highest area of risk is lubrication. The oils must be able to take the high temperatures. The suggested investigator in the material research and lubrication is ARL with TACOM support, of course, of testing. A plan of attack: We want to look at the incremental approach of how, every time you improve a parameter on that engine, it affects the total system and engine. If you increase one parameter a little bit, how does everything else in the engine get affected. We are currently testing existing materials, but we need to be testing and doing research basically on more advanced materials.

Ostberg: Richard Turbent is looking into the solid built lubricant because none of the other lubricants or oils could meet the temperature requirements in a true multiprojection situation. That's been one of the major problems with that program.

Cathey: Continental already has a program on this, and so does Mitsubishi.

5.2.1 Comments About Incremental Approach. If the incremental approach seems to be what we've been trying all along and it never really gets us to where we want to go, I think we really have to jump

in. Are we working toward a couple-year timeframe to get a power plant built and get some data out of it in order to reach our goal of 2010?

There's a good argument for that, but I think one needs to be careful about being negative about incremental approach. What's wrong, I think, most of the time, with the incremental approach is not the incremental approach; it's the off-again, on-again funding. It's that you're trying to take small steps, but there's no continuity.

I don't think it's the approach, per se. We need, like John (Frasier) said yesterday, to set some vectors in motion, and then just stay with it.

I would like to elaborate a little bit about what we meant by incremental approach. Adiabatic means that you don't have any coolant for heat transfer other than for the exhaust and that's probably impossible now, so we assume that you would have existing ceramic or alloyed engines that are higher temperatures than the conventional. And you would reduce the amount of cooling necessary, and you would still enclose and insulate the engine so that the only heat that came out was the exhaust and whatever was necessary to bring that temperature to the existing technology. And as the technology improves in temperature, you reduce your coolants until you have an adiabatic minus exhaust.

5.3 Recoil Systems.

Proponents: Dr. Ronald Gast, Dr. Lawrence Puckett, and Dr. Kailesam Iyer

Presenter: Dr. Ronald Gast

Let's review the recoil system again (Figure 5). Basically, the recoil system is a highly nonlinear device. It's a storage component, which is the gas spring, a nonlinear spring, and also the damping component, which is basically a hydraulic cylinder, which pumps fluid over a variable orifice. And that's the reason why you see this taper here; that's to indicate that the orifice is variable and it gets smaller as the cannon goes further in the battery and slows down. So, that's how we can maintain our flat recoil pressure load. There are some problems with hydraulic systems. The first being, you've got hydraulic fluid and you have to seal it. Typically we probably have 10 different seals in one brake component. And also, we have to make sure we don't lose hydraulic fluid, so also hooked onto each cylinder is a

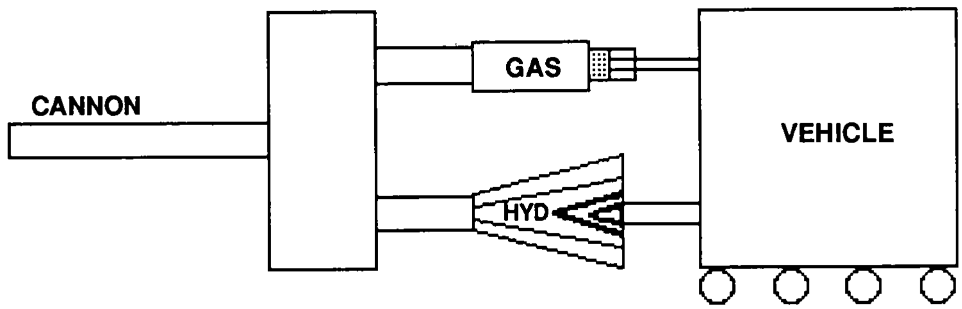


Figure 5. Present recoil system.

replenisher, a pressure device which makes sure that the cylinders are always full of fluid. If you lost fluid and fired the gun, the gun would go out the back of the vehicle; you wouldn't want that to happen. The gas side of it is not quite as bad; the gas spring is self-contained. We've had very few problems with that. What my idea was, why don't we just get rid of this hydraulic cylinder completely, and substitute a reverse EM-type device. In other words, in strict EM, when you're trying to propel a projectile you pulse a coil, it drives a magnet, and boom, out you go. Well, there's no reason why you can't do the same thing in reverse. You pulse a coil, you throw a magnet, and you catch it; so, what's the difference? It's really the same idea. So, basically, that was what I thought about. Figure 6 is, again, my poor schematic representation of how the thing would probably work. Basically you've got your vehicle here; possibly you could have a magnet projecting. Over on the other end, you've got this cone shape with a coil wrapped around it. And the reason for the cone shape would be that you would induce a stronger field-reversed EMF field as the gun got further into the battery condition. In other words, if the magnet got close here, you'd have a stronger reverse EMF field to work on the gun. And, also as well, you may have a mechanical representation (you certainly wouldn't do it this way)—kind of a cam and follower subsection, so you could vary the current which would vary the inductive field as well. And one of the benefits, of course, is you would get rid of all the problems associated with the hydraulic system. You

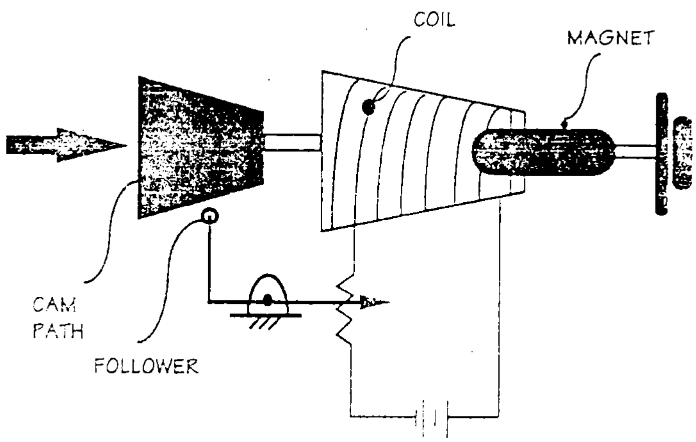


Figure 6. Proposed recoil system.

wouldn't worry about leaks, wouldn't have to worry about making sure your fluid levels were up. The disadvantages, of course, may be that the EM signature of this would have to be dealt with. You may have to shield that somehow.

Payoffs: Possible weight savings, due to the fact that you don't have to build structural pieces; the hydraulic cylinders are fairly healthy structural pieces. Each one of our brakes weighs somewhere between 120 to 150 lb apiece. Suggested investigator: ARL and Benet. The plan of attack would be the performed system concepts feasibility studies. At Benet, we have done laboratory tests on performance of hydraulic brakes for the last 15 years or so; we can probably do the same thing with the device you see in Figure 6. I don't think there will be any problem with this. We've strictly got to get the weight up to speed, and try to stop it; it's really not a big deal. But, how is this going to impact the vehicle? Probably, it will be a minimal. I mean it's not going to have the impulse to deal with; you're still going to wind up with the same type of force back at the vehicle. The only thing is, we're going to deal with it in a little different fashion.

Question: Is there any way you can convert that into another energy?

Answer: Well, we decided it wasn't worth it. But I mean there's no reason why you couldn't. I think probably now, though, it would be a lot easier to do it, if you did something like that. You know, a conversion into some other energy would be a bit easier than trying to convert it directly from what we've got here. Hydraulic heat, the heat generated from the hydraulics . . . but, yeah, it would probably be more viable for a conversion when it's in this form.

5.4 Phase Change Materials for Passive Thermal Energy Storage.

Proponent: Mr. Dana Granville

This suggestion addresses the capability to design, formulate, and apply phase change materials (i.e., materials that transform from solid to liquid to solid) for use in thermal management of diesel engines and hot exhaust gases.

Payoff: Could complement present adiabatic diesel engine research (to develop high-temperature engine materials that do not require coolants, thus increasing engine efficiency). Phase change materials could be engineered to absorb thermal energy produced by the engine at a determined temperature range to protect from overheating similar to conventional engine coolants, but at much higher temperatures and without need for a recirculating system. Thermal energy stored/maintained at such high temperatures then may be converted more efficiently to electrical energy applications and/or battery storage.

Risk: High.

Synergisms: Combines advantages of higher efficiency engine technology with lower space requirements and nonflammable materials.

Suggested Investigator/Organization: ARL-MD, -EPSD, -ACISD, -VPD, TARDEC.

Plan of attack:

- Identify current/near-term candidate materials and their continuous thermal operating capacities for application to high-efficiency adiabatic diesel engines.

- Identify, formulate, and develop candidate phase change materials for high-temperature engine thermal management.

- Determine relative effectiveness of phase change materials at determined temperature ranges.

- Develop thermoelectric capacity design criteria for phase change materials.

- Develop parametric models for phase change materials/energy transfer and storage designs.

- Determine design criteria for the phase change operating system within the size and capacity of a selected engine based on parametric models.

Issue: Energy storage/weight/power plant space envelope (weight is driver).

Transformation Into Future Vehicle Concept: Determined by decision to apply adiabatic diesel technology using current advances in high-temperature materials (ceramics, metal alloys, intermetallics, cyclic polymers).

5.5 Motor Signature Analysis Applied to Tank Electrical Use.

Proponent: Dr. Al Akerman

Any electrical device will provide feedback on the power line in the form of a very weak electric current. Presently such currents are monitored to assure proper operation of motors in remote locations in nuclear reactors. Through monitoring and feedback, motors and other devices can be operated at peak efficiency and in some cases, impending failure can be diagnosed (see Figure 7).

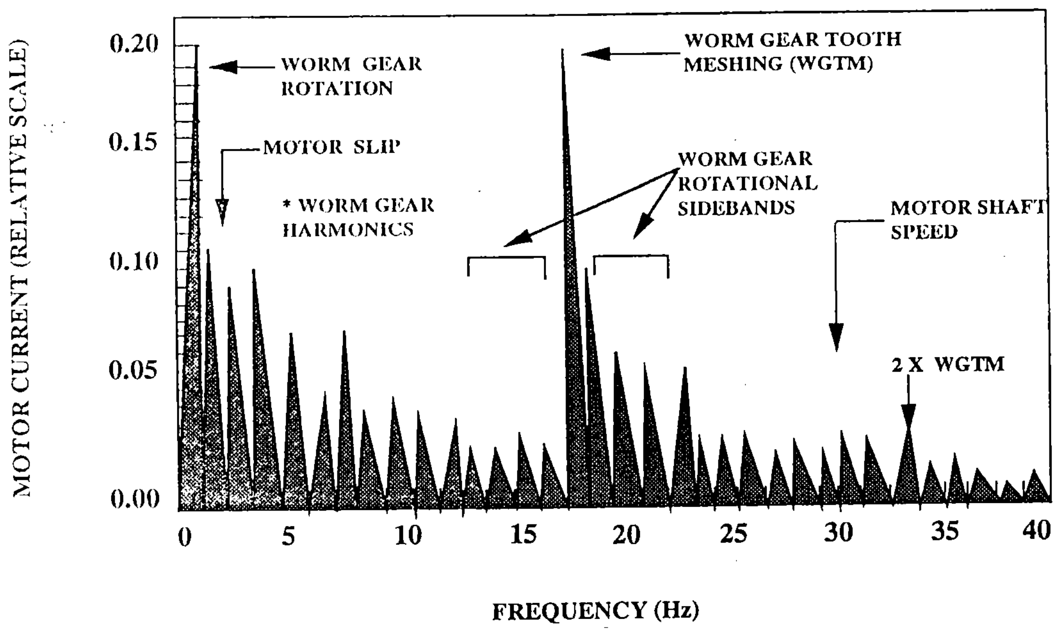


Figure 7. FFT of a demodulated electric current signal.

Risk: The risk is very low, and the payback could be very high.

Synergisms: The same technology could be applied to electric vehicles as well as all electrical systems within a tank, fighting vehicle, truck, or other vehicle.

Suggested Investigator/Organization: ARL/VPD, Oak Ridge National Laboratory.

Plan of attack:

- Determine appropriate performance criteria to monitor and acquire data from standard operating devices.

- Determine the appropriate feedback control system required.

- Demonstrate control using feedback.

5.6 Pivoted Pod/Spoked Wheel for Armored Vehicles.

Proponent: Mr. Steve Sanders

Payoff:

- Fuel economy.

- Superior (to most wheel) traction (see Figure 8).

- Maintainable.

- Vibration/shock absorption.

- Survivable (mines, small fire).

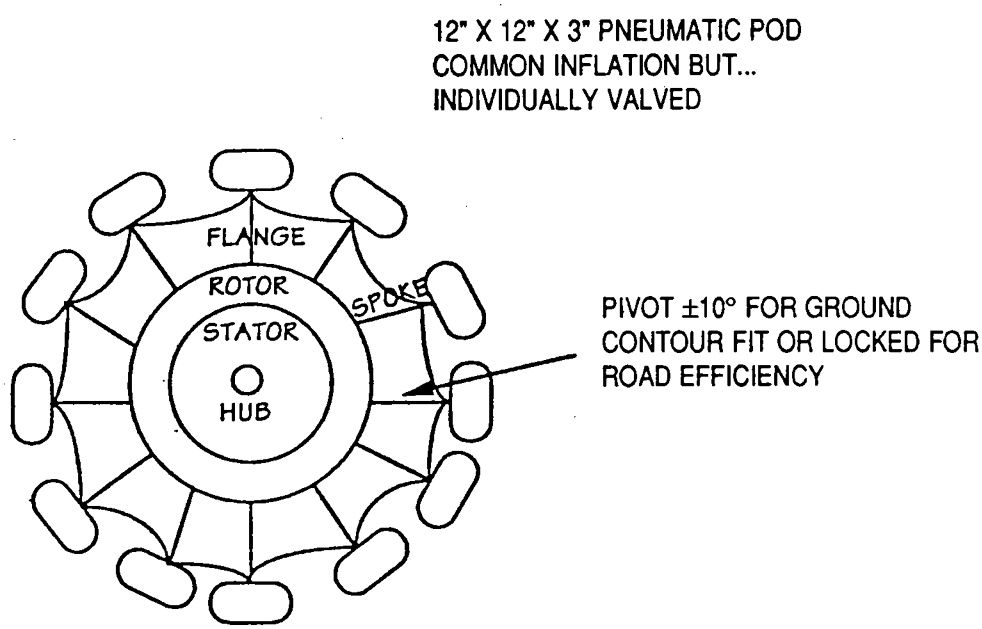


Figure 8. Pivoted pod/spoked wheel.

Risk: Low.

Synergisms: Deployment doctrine, Power plant/performance tradeoffs.

Suggested Investigator/Organization: TACOM.

Plan of Attack: Select bearings, flange, hinge, pod materials; design; engineer; prototype; tradeoff; demonstrate; spec; and produce.

Issue: Political reception, deployment limitations (mud, snow, loose sand).

5.7 Rapid Displacement Technology (Jack Rabbit).

Proponent: Dr. Z. G. Sztankay

The idea is for the vehicle to "jump" or "dodge" out of the way of an incoming round, once the predicted path of the round has been determined by sensors similar to those being considered for active protection. Approximately 1 s may be available to get out of the way. The velocities required are not excessive, but the acceleration is another matter. Explosive means might be considered. A "pneumatic foot" is another possibility.

Payoffs: Survival, lightweight.

Risk: High.

Synergisms: Utilizes sensor technologies which are similar to those for active protection.

Suggested Investigator/Organization: Somebody at WTD should be the lead. Greg Sztankay, Bruce Wallace; others at S^3I can work on the sensor(s).

Issue:

- Is this idea within the realm of possibility?

- Could the crew take the g forces of the "jump?"

Transformation Into Future Vehicle Concept: If the basic idea is feasible, the transformation should be manageable.

5.8 Chaotic Time Series Analysis to Increase Engine Efficiency.

Proponent: Dr. Al Akerman

Use Chaotic time series analysis and feedback to increase engine and propulsion efficiency.

Many systems important to engineers today are deterministic in that a knowledge of the history of operation allows the prediction of future operation. If the system is nonlinear in nature, there is the possibility of chaotic or partial chaotic behavior, which is deterministic but leads to computational difficulties and ultimately to difficulty in controlling the system at peak efficiency.

An example of such a complex engineered system is the internal combustion engine. As long as the machine is run with appropriate fuel-air mixture, the peak pressure developed each cycle remains more or less a constant. When other desirable traits are added such as low NO_x emission, ultraburn, or maximum efficiency, misfires will result.

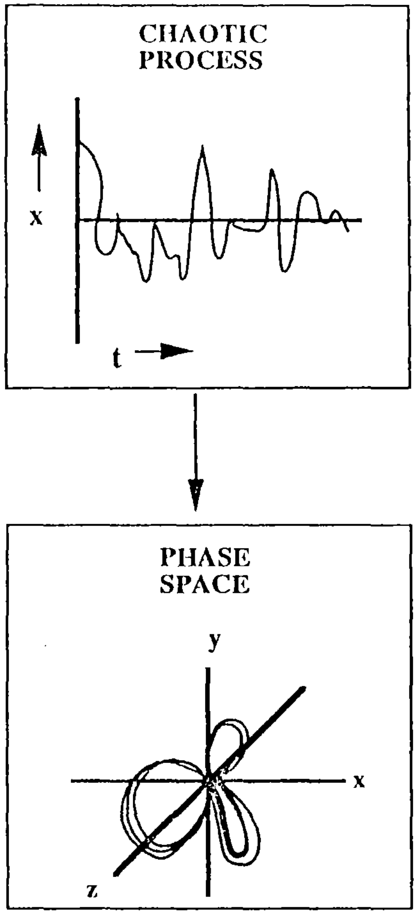
It is proposed to utilize chaotic time series analysis and appropriate feedback to improve the operation of an engine (see Figures 9a and 9b).

Risk: Since this hasn't been demonstrated, there is the possibility that it won't work or that the optimum control mechanism won't be found.

Synergisms: The techniques may have applicability in other systems as well such as recoil control or electrical subsystems.

Suggested Investigator/Organization: ARL-WTD, -ACISD, -VPD, Oak Ridge National Laboratory.

CHAOTIC TIME SERIES ANALYSIS PROVIDES A MEANS OF
EXTRACTING USEFUL INFORMATION FROM CHAOTIC SIGNALS
(SIGNALS FROM NONLINEAR PROCESSES)
WHERE TYPICAL ANALYSIS IS INADEQUATE



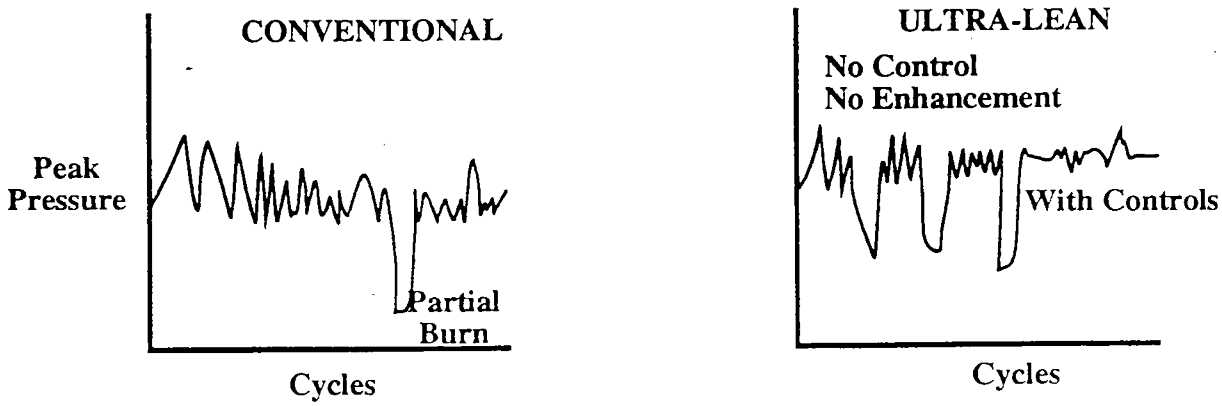
- CHAOTIC TIME SERIES ANALYSIS TRANSFORMS DATA FROM THE TIME DOMAIN TO PHASE SPACE.

- THE RESULTING PHASES PORTRAIT IS THEN ANALYSED

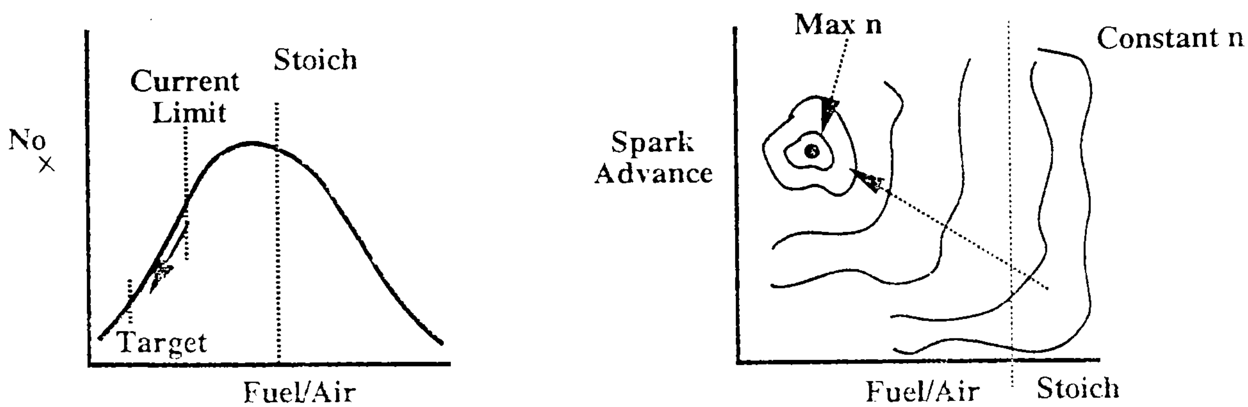
  - DIMENSION
  - ENTROPY
  - LYAPUNOV SPECTRUM

Figure 9a. CTSA provides a means of extracting useful information from chaotic signals (signals from nonlinear processes) where typical analysis is inadequate.

Goal: Extend Lean Limits
Problem: Increased Cyclic Dispersion
Strategy: CTSA identifies Structure of Cyclic Dispersion, Learn, Controls



Control Dynamic Cyclic Dispersion That Bounds Lean Limit



Potential Result: Extend Lean Limit NO_x Reduced, Efficiency Increased

Figure 9b. CTSA shows promise in engine control strategy.

Plan of attack:

- Determine appropriate performance criteria to monitor and acquire data from standard operating engine.

- Determine the appropriate feedback control system required.

- Demonstrate control using feedback.

6. LETHALITY IDEAS

6.1 Fully Exploit Storage/Logistics Advantages of LP.

Proponent/Presenter: Dr. Robert J. Eichelberger

It's hardly a new technology idea; to my personal knowledge it's been going on for almost 40 years, and it probably had proponents before that. It's a technology whose time has come, and come, and come, and come, but it has never actually been brought to fruition. In the present context, its main advantage for the individual is twofold—the opportunity to reduce the volume required for stowage and survivability. The very fact that it's liquid allows one to stow it low in the profile of the vehicle, where it's not likely to be hit, and in odd corners, so that it doesn't take up valuable space; and, of course, its stowage is very compact. The material that's being used for LP gun systems nowadays is also very insensitive to the types of ignition that are likely to occur on the battlefield, so, if one wants to be radical, one could even stow it in places where it could add to the armor protection. The time is right for exploiting because it's already being developed in an artillery piece (AFAS). The double usage of the same propellant for armor and for artillery would offer a great attraction for resupply and for logistics purposes. The advantages, as far as a ballistic efficiency is concerned, are relatively small, but they're real. One can get the more efficient ballistic cycle with LP, a longer pulse with a lower peak pressure. It has a tendency to burn at lower temperatures so that gun wear would be reduced. But those are really secondary benefits compared with the benefits for resupply, for transport, and for cost. The material can be produced very cheaply by commonplace chemical engineer plants. It doesn't required a special plant. It could be produced in quantities required for peak wartime use, by relatively few plants. It's a very attractive material from that point of view.

Transporting liquids is obviously very much easier than transporting solid propellant cartridges, especially since it isn't classified as an explosive. It can be transported in the same fashion as fuel. The reduced hazards I've already alluded to. The material would pose no additional burden on the soldier, no additional training, or anything of that sort.

Some of the problems that still would have to be solved are those associated with the filling of the breech of the gun. This is high-pressure pumping and transfer technology. It's not an exotic technology; it's just something that has to be addressed. And probably, the current state of the art in the business would have to be advanced to the extent that the pumps, the transfer equipment, ought to be miniaturized some. As it stands now, in the artillery piece they take up a good deal of space, and it would be nice if they either moved to less obtrusive locations, or reduced in size, or both, and if their reliability were improved. So, those are major issues, and the only extension of technology required is in that engineering domain.

The risk: We assess it as a medium to low risk. The risk would be incurred if this were subjected once again (it has already been subjected once) to a demand for time-programmed demonstration. What it needs is a serious engineering approach without a timescale that you have to demonstrate the thing. It needs to be done properly, in other words.

The plan of attack: I presume there is a contractor who has done most of the work in recent years on liquid propellant gun systems. That contractor needs to be given the assurance of continued support, and told to solve the problem, and to get whatever help he needs or can get to do so. Unless there are questions about any of this, that's the end of that story.

Puckett: I would like to endorse that, and add two or three points to it, since this is on the record of the meeting. We have had a contractor do a tank systems exploitation study on the subject of LP, contrasted with conventional solid stick propellant. And for a 140-mm gun system, all other things being equal, the weight reduction afforded by the LP system that Bob has just described is around 3.5 tons. Now, that's point one. Point two: if we could solve the problem with the bulk-loaded LP system, which does not, as we know it, entail the mechanical complexity of the fuel injection system, that would reduce the weight by an additional ton, and space accordingly, because the regenerative system here is large. Point three: the U.S. Army holds the patent on a new bulk-loaded concept and we have it in our research program. We've had it for about 1 1/2 years and for the first time, it is showing promise of controlling

the old Rayleigh-Taylor instabilities and Helmholtz instabilities. We need more emphasis on that benefit to get money into that aspect of the LP program.

Eichelberger: I would like to add a philosophical point. We're really proposing that the Army get busy and exploit a technology that isn't really new, at the same time that several newer technologies—the electrothermal gun, the electric guns—are being worked on. I think it's time the Army accepts that staged progress is the thing, that you shouldn't always stand pat until you can make a quantum leap. We could have had LP guns in use 15–20 years ago if it hadn't been for the stop-and-go type of funding that was given to it. As a matter of fact, there have been times in the history of LP systems when the laboratories were absolutely forbidden to work on it. So, with that kind of a history, you don't make much progress.

6.2 Replace KE With CE or Missiles?

Proponent: Mr. William Haskell

Presenter: Dr. C. Anderson, Jr. (NOTE: the MICOM participant was unable to attend; therefore, missile expertise was not presented or represented here.)

Can we eliminate large KE weapons and replace with missile or CE, and maybe have an advanced 30- or 50-mm AP automatic cannon on the vehicle? The first thing we did was address missile vs. gun. There are a lot of doctrinal issues here. I'll come down here in the middle first, and just say that this is probably a continuous exercise in tradeoffs between missiles and guns, and so, no matter what is said here today, it's going to be a continuous exercise for that.

Bob Eichelberger pointed out that when you look at HEAT vs. KE, because of the reactive armor that can be put on right now, the HEAT round is pretty much taken care of, so now KE is the real threat. Well, if that's the threat, that means you have to go to a KE missile and all of a sudden, the advantages of a missile over a direct fire weapon aren't all that great anymore. I think, certainly you've seen from Desert Storm, you can acquire a target at a great distance, you're very accurate, and you can deliver a long rod to it. So, some of the advantages of a missile disappear when you have to go to a KE.

Issues with rate-of-fire—big issue there. You can't do a lot of shocks with missiles very fast. Engagement distance: missiles take a certain amount of time to come up to speed, and a tanker is worried

about, all-of-a-sudden, very close combat. And he's not going to want to give up velocity there. Another issue with missiles is the number of rounds that you can put onto a tank. We had a guy who actually was a tanker in our group. What about training cost? He said that the missile probably needs to be autonomous because trying to guide it through its plume and everything else, is a difficult problem. That makes it very expensive; now it's so expensive that a unit can only fire one or two during an entire year, so training gets to be a big issue here.

New skills required: Somebody was talking about the delicacy in handling these missiles relative to the way that the KE rounds are handled inside tanks. Missiles may be more susceptible to countermeasures. That doesn't mean that missiles aren't important. Somebody said that a missile could go after something that's not in line of sight. That's good, but that's not the mission of a tank. So, we think that the gun has to stay on a tank. But, in the spirit of that then . . . can we do something? Now, the question is, if you want to make a lighter tank, you've got to address—where is the weight of the tank? It's in armor, and it's probably also in the gun system. Now we've heard about people going to a 140-mm gun. How about if you go to a smaller gun? There are a lot of advantages if you do that. There are lower weight, less recoil, and everything associated with that. Smaller ammunition means storage of more ammunition. Go to less of a gun, and we talked about things like a reduced profile; that can help you. There is one big issue with that, though—you need to increase the lethality for a smaller gun. What that says is, you need to exploit technologies that are here now. Now, that doesn't mean that they're ready to be fielded, but there's been active work going on. Somebody's talking about, particularly with smaller guns, how it becomes easier with the continuous muzzle reference system, or precision aiming technique [large guns have been the drivers for the Continuous Muzzle Reference System and the Precision Aiming Technique]. People are already looking at how to reduce the weight of a 140-mm gun, and I guess we're hearing right now that a 140-mm gun with the new technology is the weight of a 120-mm gun. Well, you could apply that same technology, then, to a smaller gun or even to the 120-mm gun. Perhaps new barrel geometries. Certainly computational capabilities have increased so much over the past 5–7 years that a lot of work can be done in the theoretical realm to help you exploit a lot of these technologies, which were not there when the 120-mm gun was designed.

Muzzle control and targeting: There are advanced penetrator concepts right now. There's a lot more work that needs to be done. But that might allow you to make a lethal 90-mm fired weapon, such as the extending, or telescoping rod. You might need to get more velocity out of a smaller gun in order to get

lethality; that means advanced sabots. People are already working on advanced penetrator materials which can take the launch loads.

Plan of attack: Really, it's engineering R&D. This is a no-lose situation for somebody like ARL. Because anything that you do here that goes for a smaller gun—all that technology is directly applicable to a 120-mm gun or a 140-mm gun, so it's a winner, no matter what. If we were trying to assess the risk, there's probably no technological risk. The big question is, if you go to a smaller gun, are the payoffs great enough to allow you to go to a smaller gun?

Eichelberger: I think you ought to emphasize that we're talking about a higher pressure gun here. The new materials technology is not for weight reduction in this stage, it's for strength improvement.

Anderson: Yes, and in strength improvement, the LP technology we talked about would apply here. There are a lot of advantages of doing this, and this is certainly an engineering R&D type effort.

Question: With a smaller diameter, would there be a sacrifice in the range?

Anderson: I don't see why.

Question: Increase the velocity and maintain the accuracy and improve the accuracy?

Anderson: Yes . . . maybe keep the velocity the same. You might want to see if you can increase the velocity. All that falls back into the barrel technology, the breech technology, what the sabots can handle. People are already talking about composite sabots to handle the launch loads. People are demonstrating that rods can extend in flight to give you long L over Ds, but launch compact. And, if you can go to a smaller gun, you affect a lot of weight requirements. Nobody wants to give up the lethality. That's the central issue. But interestingly enough, I think that with all these things coming on line, and people working in these technologies, there's a good possibility that something can be done in this area.

6.3 High-Energy Laser to Detonate Reactive Armor.

Proponent/Presenter: Mr. Oliver Cathey

High-energy lasers—by high energy, I mean multiple KW, not MW lasers. To cook off bombs in submunitions for ordnance disposal, they found that in a matter of a second or so of illumination, they can set off explosives. So the theory behind that is you might be able to use a high-energy laser to illuminate the surface of an enemy tank that has reactive armor on it and just cook it off. That allows CE rounds, or KE rounds, then, to go into a surface that's not protected by ceramic armor. The primary issues associated with this are twofold. One is laser spots tend to be small, so if you did cook off the armor, then you have to hit it with a round, or take longer to strip all the armor off. Because reactive armor tends to have voids in it, there's some question about whether it will work at all. Obviously, if you get enough power in the laser, you can cook off anything. And there is the question about how powerful you have to make the laser and how much power it would consume. Those are two primary issues. There are some synergisms. This will blind the operators; we're not talking about lasers that goggles work against. We're talking about vaporizing the face of the guy; I mean glasses and all if he looks at it. You are not going to save yourself with goggles when you're looking at this laser. It kills the operator, probably, if he looks at it. It will also destroy the sensors, probably, and all of the RF sensors as well. It will strip all the sensors off of the outside of the tank. And you can do this at lower power.

Another synergism would be, that if you were lasing and you happen to have a laser-guided munition of some kind, it could home on the radiation. Put laser-homing devices on the CE rounds and then home on the radiation where you're stripping the armor off. The investigator for this would certainly be ARL; my guess is the initial plan of attack is find out if this makes any sense whatsoever, because there are some very serious issues like—will it destroy the armor? That sounds easy to test, and there are lasers around that you could use. I would say the first thing you do is to find out whether it will destroy armor.

It takes a lot of power to run one of these things, because they are not efficient at the moment.

In all probability, dealing with heavy armor, you probably want to use pulse lasers. And pulse lasers don't tend to bloom as much. The pulses are extremely short, so they're more difficult to see. The most

effective wavelength is probably green, which is highly visible. So there's a question about a tradeoff in effectiveness and visibility, and you run into a lot of safety issues if you don't make it visible.

Question: Conceptually, would this be a dedicated vehicle?

Cathey: That's a good question. In other words, would you have an armor removing vehicle? Why not? That way, you could get a fairly large diameter spot by devoting the entire energy of the vehicle to armor removal; you could strip a whole lot more armor with a dedicated vehicle than you could with a scab-on kind of device. But the MICOM device is small and would fit within the power budget of the main battle tank as an auxiliary; that's what I was thinking. The other thing is we have to start right now with this because you'll never get a ray gun in 15 years. This is a long lead item.

6.4 Reduce Gun Size, Retain Lethality With Advanced Ammo, or Sacrifice Some Lethality.

Proponent: Mr. Dennis Orphal and Dr. Charles E. Anderson, Jr.

As a result of the Armor/Antiarmor (A3) Program a number of promising advanced KE concepts have been identified. These include the extensible rod-tube and segmented rods as well as other less investigated concepts.

- Mature these concepts.
- Initiate analyses/design to examine the potential of these new KE penetrator concepts to allow adoption of smaller main gun (say 75–90 mm) while maintaining required lethality. Apply all the advanced gun/materials technology developed/used for the "lightweight" 140 mm.

Payoff: Weight reduction and/or increased lethality.

Risk: Medium/high.

Synergisms: Extends/matures previous A3 research on advanced KE penetrators. Extends/applies advanced materials/design results from the lightweight 140-mm program.

Suggested Investigator/Organization: ARL, ARPA (if possible), ARDEC/TARDEC, appropriate contractors.

Plan of attack: Sustained research program to mature existing advanced KE penetrator concepts, including hydrocode calculations and small and full-scale testing. Sustained research program to develop additional advanced KE penetrator concepts.

Issue:

- Can lethality be achieved with significantly smaller and lighter gun by using advanced KE penetrators? (DRIVER)

- Continue to improve effectiveness of KE penetrators through advanced concepts and supporting research.

- How much weight could be saved for total system if gun reduced to say, 90 mm?

6.5 Use Steam (Based on Fuel Coolant Interaction) as Propellant.

Proponent: Dr. Al Akerman

Payoff: Fuel-Coolant Interactions are most famous for their potential to create havoc in nuclear reactor accidents. Under the right conditions, enormous energy is released, though typically at a slower rate than with gunpowder or modern explosives. A metal is heated in contact with water. The excess heat generated turns the water to steam and provides the motive force (see Figure 10).

Risk: Moderate—fuel-coolant interaction would need to be demonstrated for the specific application.

Synergisms: Use would allow storage of shells with little or no chances of accidental discharge during use or in the event of a direct hit by the enemy. Reaction materials could be stored in the walls of the

EXAMPLE DEVICES

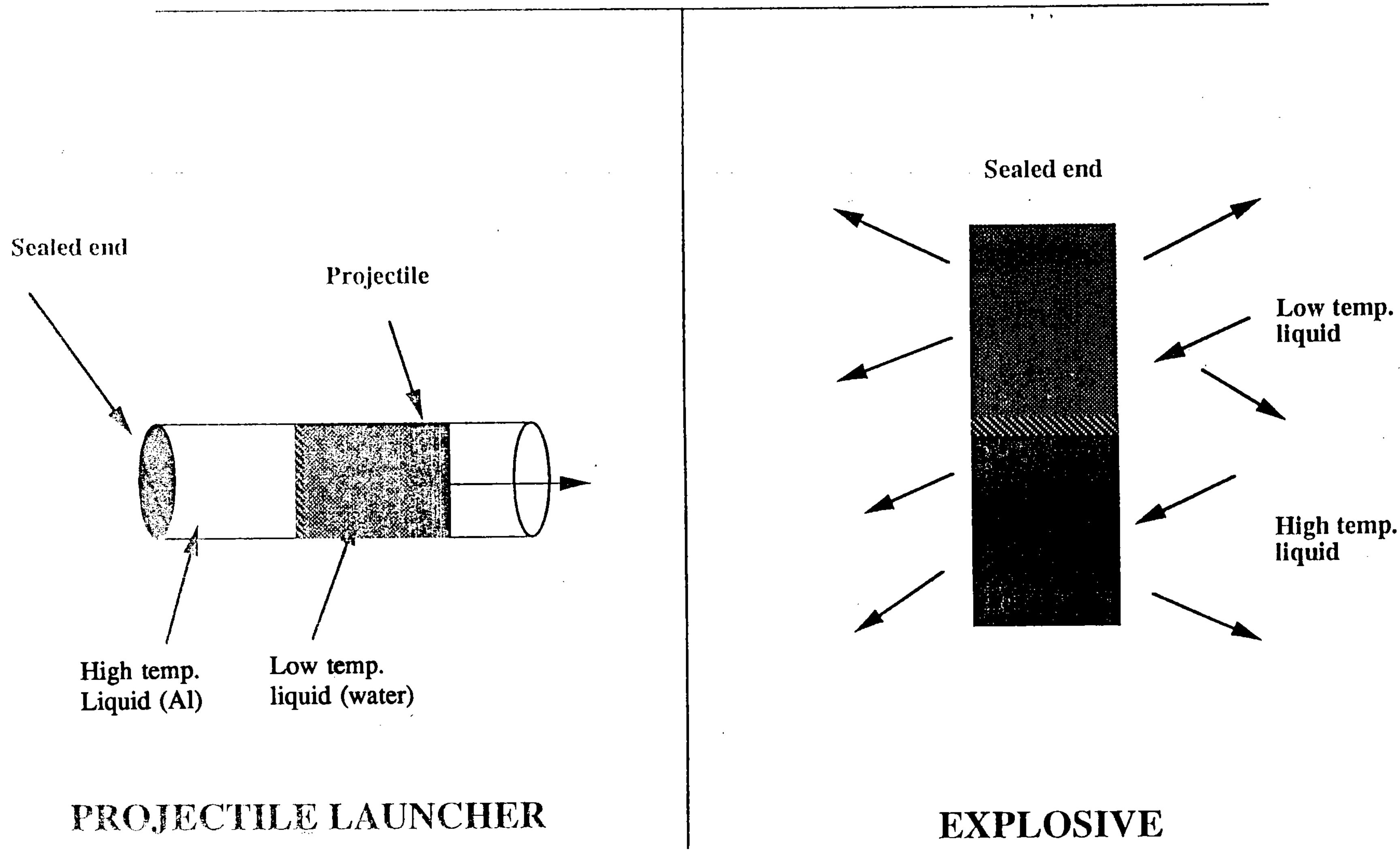


Figure 10. Steam propellant.

tank, providing additional shielding until needed during battle. Other advantages may stem from an ability to control recoil.

Suggested Investigator/Organization: ARL/WTD, Oak Ridge National Laboratory.

Plan of attack:

- Build a gun barrel with firing chamber suitable for demonstrating the utility of FCI.

- Determine the scaling laws that will apply, the efficiency, and the amount of energy utilized compared to the energy required to initiate the FCI reaction.

7. OTHER IDEAS

7.1 NBC: Biosensors to Activate NBC Countermeasures.

Proponent: Dr. Oliver Cathey

Biosensors are now available which can detect specific chemical and biological agents in part per billion quantities. Liquid decontamination agents with high specificity are also available. This concept would use a bio-sensor to detect and identify NBC agents and then activate a sprayer located on the outside of the tank to spray the tank down with the right decontaminant before any of the NBC agent could penetrate.

Payoff: NBC gear greatly reduces the efficiency of military personnel (not to mention surviving an NBC attack).

Risk: High. Biosensors of this type are at the leading edge of the state of the art. Some of the currently used decontaminants are caustic.

Synergisms: Unknown.

Suggested Investigator/Organization: ERDEC.

Plan of attack: Unknown.

Issue: Lots.

7.2 Commo: 60-GHz Radio for Communications Between Tanks.

Proponent: Dr. Oliver Cathey

Use 60-GHz for a tank-to-tank close-in communication radio. The system would reduce RF signature and would have extremely wide bandwidth which could allow tanks within the same battle formation to share voice, video, and all of their environmental sensor data.

Payoff: A radio operating at 60 GHz cannot be detected by ESM sensors. With current radio frequencies, tanks and troops can be readily located on the battlefield by remote ESM receivers and subsequently attacked. All three U.S. services deploy airborne sensors for this purpose. This is one of the primary missions of the U.S. Army's RC-12K and EH-60A aircraft. In addition to the U.S. 10 other countries (not all of them our friends) manufacture ESM equipment for this purpose. A 60-GHz signal is quickly absorbed by oxygen in the atmosphere. So much so, that at a range of 2 km or more, even a powerful radio cannot be detected. Although remote sensors are foiled, tanks close together can communicate. The signal bandwidth available at this high frequency is easily sufficient for 20 or more video channels. So, in addition to voice, tanks in the same formation could share virtually all their data. This results in a distributed sensor system in which every tank in the formation can have the view of the battlefield of the tank in the best viewing position.

Risk: Medium. 60-GHz transceiver technology is well developed for space applications. There is some risk in translating the equipment into low-cost hardware.

Synergisms: RF signature reduction and battlefield awareness enhancement.

Suggested Investigator/Organization: TARDEC.

Plan of attack: Design study, prototype, field test.

Issue: Cost. Sensor/display integration.

8. PHILOSOPHICAL COMMENTS

8.1 Management of Innovation.

Proponents: Dr. Robert J. Eichelberger, Dr. Charles E. Anderson, Jr., and Mr. Dennis Orphal

The recent Future Technologies Workshop sponsored by ARL and TARDEC was presumably intended to elicit new technological concepts or ideas for exploitation in future armored vehicle research and development. In light of that perception of the purpose of the workshop, it is deemed appropriate to comment on the conditions that foster innovation in the research and development environment.

There are a few basic axioms pertaining to management of innovation, which are generally accepted by experts in technical management, but are little observed in fact. Among these are the following:

- Innovation cannot be planned in advance.
- Innovation is not subject to scheduling or *a priori*, detailed justification.
- Innovation thrives in a "technology push" environment, not in a "demand pull" situation.
- Micromanagement is lethal to innovation.
- Very few really innovative ideas can be thoroughly tested in 12 months, or 24 months.
- Really innovative ideas seldom have clear-cut "commercial" application (in the present context, read "military" application) immediately, although they usually arise from association with work being carried out by the "inventor."
- Innovative ideas kept in limbo for any length of time awaiting availability of resources for their exploration have a way of atrophying.
- The "proof of principle" resulting from initial exploration of an innovation has a reasonable probability of success only with steady application of resources.

- Critical evaluation of innovation should be conducted only at infrequent intervals and by groups of peers (of the innovator[s]), not by staff or management personnel (except local laboratory management).

- Requiring systems engineering justification of an innovative idea before proof of principle is counter-productive as well as highly questionable of quality. After proof of principle, systems engineering is essential for determining the best means of exploiting the innovation and the most profitable directions for further development.

We believe that the research environment in the government in general, including ARL and the RDECs is generally not in accord with these principles and thus not conducive to innovation by either the in-house personnel or their contractors. Assuming this is true or at least contains elements of the truth, what can be done by the ARL to improve this situation?

The role of the "user" community in prioritizing planned projects amounts to a veto power, and constitutes the strongest of "demand pull" conditions imaginable—a management method that reduces innovation. This could be counterbalanced with a strong "Tech Base" program. The technology base has been eroded within the Army laboratory system. Although the selection process for contracts awarded and administered under the auspices of ARO is weighted by priority needs of the Army, the basic research is usually very academic with little near-term applicability. There is a critical need for a robust Tech Base program where fundamental issues, conscious of applications but not driven by a specific system, can be addressed. Innovation and innovative ideas will then emerge naturally out of the fundamental understanding of the mechanics and physics that results from the Tech Base effort.

We believe that examination of most so-called Tech Base programs throughout the DOD community will reveal that they are really dependent on funding for whatever the latest "major system" is—ASM is a pertinent recent example. A true Tech Base program must be independent of major systems for its base funding. This is required both for continuity—a very key element for successful innovation—and flexibility. Regardless of all the evidence supporting the value of Principal Investigator-originated research at what the DOD calls the 6.1 and 6.2 level, we seem not to be able to establish and sustain such programs. This situation must change if we expect creativity and innovation on other than a random basis. Creative and innovative ideas simply come from creative and innovative people, and these people must

know that their efforts and ideas will be appreciated and supported; otherwise, the best people will simply apply their talents elsewhere.

Creative people are identified by their ideas, not their employer or their geography. The ARL must be willing and enabled to actively solicit and fund creative people and their ideas regardless of whether they are employed by a Government laboratory, university, industry, or even another service. And the creative people must know that they will be well received and treated by the ARL.

Another idea of potential improvement is an increased emphasis on ILIR. It is our understanding that ARL has yielded its share of the ILIR fund to the RDECs. This decision should be reexamined. Despite the tendency of high levels of management in the Army to mismanage that fund, it still offers the best means of quickly providing funds for exploration of new ideas. The perpetual cycle of planning in advance of the use of every dollar, and the subsequent micromanagement to assure that no funds are misspent, seems designed as though to stifle innovation.

The role of local management in determining the application of resources (people, equipment, as well as funds) has been eroded by the multiplicity of staff positions and offices created to oversee and "coordinate" work in specific technological or application areas. Unless very bad decisions have been made in selecting the local management personnel, they are by far the best equipped and situated to decide how best to use the available resources and to judge the quality and the utility of the work being done under their management. They are also best situated to provide <u>technical leadership</u> instead of just management or administration.

We suggest that a useful potentially future function for ARL would be a "workshop" on the encouragement of innovation within their program.

None of the previous should be construed as critical of the Future Technologies Workshop just held. It served a useful purpose, eliciting a few really new ideas (mostly demonstrably nonstarters upon critical evaluation), exposing potential applications of existing technologies in new ways, and providing some support for the aggressive development of relatively old technologies in areas in which the need is urgent and "innovations" are likely to take too long a time for fruition. That is the most that can be expected of a short-term gathering of the sort. Planned follow-ups may well elicit still more useful ideas.

8.2 Multidisciplinary Optimization.

Proponent: Dr. Gary Farley

The next generation of armored vehicles will be unlike any of its predecessors. Recent changes in global politics, changes in military doctrine, and the economy of the United States will greatly influence the design of these vehicles. New technologies such as the use of new materials (titanium or composites), electric power train, new weapons (LP gun), and active and passive armor and signature management systems will be widely used or at least seriously considered in design tradeoff studies. With this multitude of new design parameters and constraints and the lack of understanding of their mutual influence, the designer will have difficulty in making rational tradeoffs and the time required to conduct these studies will become prohibitive.

One approach to solving the problem of integrating new technologies into a cost-effective design in a timely manner is through the application of multidisciplinary optimization. Multidisciplinary optimization is a proven technology by which it is possible to integrate different technologies into an automated design process. The resulting designs are generally more efficient and are achieved with less expenditure of resources than designs produced using conventional methods. The barriers to the wide spread application of multidisciplinary optimization to the design process can be attributed to the lack of knowledge about the process, belief that the technology is immature, belief that current computational power is insufficient, or fear that its application will replace the designer. Once these barriers are removed, designers have found multidisciplinary optimization to be an indispensable tool which allows them to make more efficient designs in less time. It is also used as an educational tool facilitating a better understanding of the cause-effect relationships that drive a particular design.

The payoffs of the broad application of this technology in the design process are only partially quantifiable today. Based upon limited studies, the reduction in manpower as compared to conventional design practices, excluding the original computer code development, is more than an order of magnitude. Therefore, it would be reasonable to expect that a 50% cost reduction in the design process could be realized while potentially achieving further reduction in vehicle weight and manufacturing cost. The unquantifiable aspect of the application of this technology to the design process is it may enable us to apply new technologies to the vehicle to increase its lethality, survivability, or maintainability that

otherwise may be unobtainable. This enhanced capability may be achieved through the reduction of resources expended during the design phase, allowing for the performance of additional trade studies.

The risks associated with the development of computer codes to perform the multidisciplinary optimization are low. Sufficient computational power exists, optimization algorithms are proven, and many of the analysis tools used in the manual design process exist in a computer code. Therefore, it is only necessary to integrate the different disciplines together. However, risks of misuse of this technology exist. This is related to the problem of "garbage in - garbage out." An unknowledgable user can input inappropriate design conditions (garbage in) resulting in a worthless design (garbage out).

The ARL should fund the development of a test bed multidisciplinary optimization code that is used to quantify the capability and to provide a framework from which industry can build their design tools. This test bed code would not have to be all encompassing but could integrate selected technologies. Once the code was developed, blind demonstration tests would be performed to quantify capabilities.

VSD, in collaboration with NASA, has been active in the development and application of optimization technology. VSD could be the integrator of the different disciplinary analysis codes into the multidisciplinary optimization code. Other ARL Directorate and industry representatives would participate to provide the appropriate analysis tools, defining the constraints and design parameters and conducting the blind demonstration tests.

8.3 Need for Combined Efforts to Look at Optimum Hull Designs.

Proponent: Mr. William Haskell

There is a need for combined efforts to look at optimum hull designs/plate obliquities, shaping for combined structure, and armor and signature optimization.

To meet future vehicle weight goals, all aspects of the vehicle design and performance must be considered from day one. Passive armor designers should coordinate with signature management people to select shapes and obliquities that offer the best combined performance. Manufacturing techniques required for higher volume production, not prototype production, should be considered along with armor and signature management. There is an appearance that researchers in different technology areas work

independently on their systems and then the vehicle designer tries to force this all into the vehicle concept. This could lead to vehicle weight growth. Manufacturing cost usually increases as the program goes from prototype development and testing to full-scale engineering development leading to production. Changes in vehicle design concept may increase this already long cycle from concept to production.

8.4 Systematize a Technology as Early as Possible.

Proponent: Mr. Joseph Ploskonka

Most of the ARL is in the business of developing various technologies that may be used either to upgrade current systems or to be a dominant feature of a next generation system. To obtain support (funding) for developing any technology, one needs to show how the technology will impact system effectiveness as early as possible. However, a systems analyst can not evaluate the impact of a technology on a system's effectiveness unless he has information on how the technology will be integrated into a weapon system. For example, if one were tasked to determine the increase in survivability that one can expect from reactive armor, then the analyst would need to know (as a minimum) where the armor is to be located and the effectiveness of the armor against the threats of interest. Thus, the technologists of the ARL need to develop (conceptualize) how one would "systematize" a technology. Also, the "systematization" of the technology is needed by TARDEC to determine how to incorporate the technology into a vehicle and how to interface the various "systematized technologies." It is important to note the following on systematization of the technology.

- The technologist (with help) needs only to develop a plausible way to "systematize" the technology and not get overly concerned about finding THE way to systematize the technology.

- In "systemization" of a technology, the technologist should take the liberty of assuming all breakthroughs that don't go against the basic laws of physics and/or chemistry.

- Once it has been demonstrated that a technology can be "systematized" in hardware (laboratory test fixture), the technologist, with help from the user, PMs, etc. must start to consider how to "produce" the technology so it can be both manufactured and is usable by the troops in the field.

It appears unlikely that there will be a single technology breakthrough that will be the sole reason for developing a future system. For this reason, one must develop vehicle concepts utilizing the various new technologies. Once the vehicle concepts are developed, the systems analysts (SLAD, AMSAA) should evaluate the concepts to determine the effect on battlefield effectiveness. It is the systems analysis of the technology integration approaches (vehicle concepts) that provides the focus on what technologies appear to have the greatest payoff for future weapon system development programs and current systems' product improvement.

8.5 Design Guides.

Proponent: Mr. William Haskell

Previous armored vehicle design guides for hull and turret structures should be considered, but not used to set performance standards of advanced materials applications. By forcing metallic materials design limits and standards on advanced, hybrid hull structures, the weight reductions needed to meet transportability weight goals could be negated. Advanced hybrids and composites may have strength and fatigue design limits different from metals. Hull structural rigidity limits that do not affect vehicle and subsystem performance should not be forced on future vehicle design programs.

8.6 Crew Size.

Proponent: Mr. William Haskell

The number of crew members in an armored vehicle such as a tank or howitzer has always been the subject of much debate. Army research is moving toward reducing the crew with the incorporation of systems such as autoloaders. The Army has programs, the goals of which are developing a reliable two-man crew system. Current vehicles depend on three- to four-man crews. These crews perform functions of driver, gunner, commander, and loader. This team must also perform duties such as replacing a thrown track or defending the disabled vehicle from attack by enemy ground troops. Have all groups concerned with training, war fighting doctrine, and the armor center signed off on having this reduced crew size? If a crew member is injured, can one man operate the vehicle and fight at the same time?

8.7 Assess Tradeoff for Multihit Protection.

Proponent: Dr. Robert J. Eichelberger

There are a number of user hangups that hinder innovation. The requirement for multihit capability is one of them. The question of duration in combat of an armored vehicle arose during the workshop. Not the duration of BATTLES between armored FORCES but the durability of individual vehicles in the battle. The question that must be answered by analysis, not the intuition of users who have never engaged in such combat, concerns the design and the use of individual vehicles that constitute a force. The Israeli experience at the Golan Heights was cited; the battle took several days, but how long did any individual tank continue in combat, and how many rounds did it fire, and how many hits did it take? And we should be concerned with significant probabilities of events, not 2 sigma or 3 sigma possibilities.

8.8 Assess Minimum Weight of Structure for Vehicle w/o Protection.

Proponent: Dr. Robert J. Eichelberger

The irreducible weight of a vehicle designed only to carry a weapon over rough terrain at satisfactory speed is a very useful baseline value to have. This has been estimated a number of times over the years, starting with Cliff Bradley at TACOM. When the required rigidity of the structure is taken into account, the weight turns out to be surprisingly high. The question was answered to some extent at the workshop by John Lewis. I am not satisfied, however, that the engineers have taken into account novel types of structures that could be considered, and that might offer some further reduction of weight. The ability to add on protection must be one of the initial requirements, of course.

8.9 Develop Realistic Evaluations of Tradeoffs Between Stowed Load Requirements and Time of Continuous Operations.

Proponent: Dr. Robert J. Eichelberger

Another play on the theme of user fixations. The number of rounds required in the stowed load has been constant and unalterable for many years. I have not known of any serious study of the trade-offs between those requirements and the possibilities of reducing volume of the interior, and the weight of the

vehicle, for many years. The U.S. Army carries only antitank rounds (some of them are called multipurpose, but their design is dictated by their antitank capabilities), and requires more of them than did the Soviet forces, who carried a greater variety. It is time for an objective evaluation of tradeoffs, so that innovation is not stifled by "traditional" requirements. This is really part of a general plea that ALL user requirements be subjected to the same kind of analytical examination as the engineering design characteristics. Innovation is difficult enough without being hampered by unsupported demands by one part of the community.

9. DEVIL'S ADVOCATE

Dr. Wolf Elber

As a group, Army scientists and engineers have been doing the same old thing for the past 20 years. A question that they have to be prepared to respond to is, "Why are you doing it, today?" Are you thinking in terms of the combined force? Today's warfighting doctrine is one of combined arms (air and ground forces fighting together). We need to think more freely. Instead of thinking on how to improve the tank, maybe we should think, "Can we live without the tank?" Desert Storm showed that warfare as we have envisioned it for the past 50 years has changed and may no longer be affordable. We have to do everything we can to think about how to improve the ground-air synergism. One if by air, two if by land, but we get three points if we do it together (see Figure 11).

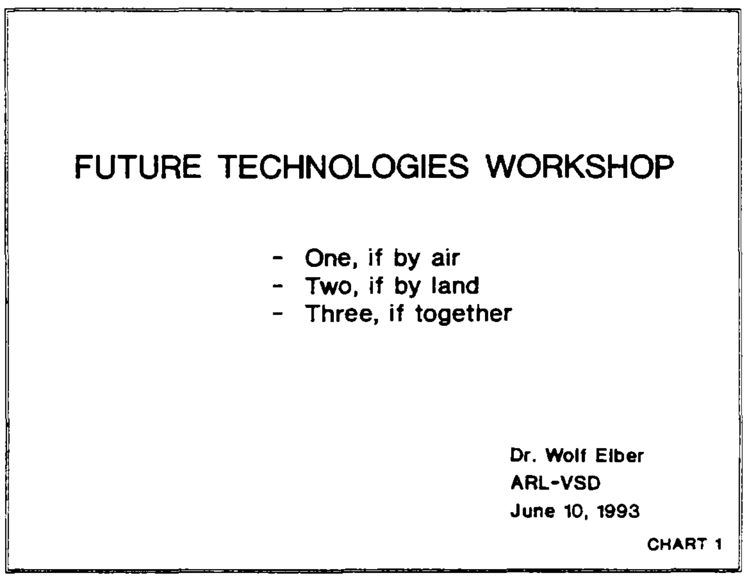


Figure 11. Title viewgraph.

As an example, look at two research and engineering loops. The thing about loops is you have to figure out how to get out of them.

The first loop (Figure 12) is the detection-detectability loop. We're in it big time. The sensors people have shown and told us that sensing capability will continue to improve by big factors each year; some gain 12 dB per year. Detection capability at sooner and at longer ranges is a reality. At the same time "Signatures" scientists and engineers are devising more and more means to make detection more difficult, but there are serious limits. The result is that the detection people are going to win. But, is that bad? We fought Desert Storm with equipment, such as Apaches which flew with no or limited low observabililty capability, no signature control. If we keep working on the detection-detectability loop and the fielding of equipment with these technologies, we're in a vicious loop. Because, by the time the equipment is fielded, it is obsolete. New research will have resulted in greater detection capability and/or protection technologies. A loop that will cost us (Defense) billions each time we go around it.

The second loop (Figure 13) involves armor/antiarmor capabilities. Thirty tons of the vehicle is dedicated to this loop. The antiarmor people can demonstrate that they can develop the capability to penetrate any armor protection (with higher energy, longer rod, larger round, etc.) At the same time, the armor/hull people can demonstrate that there are numerous ways to defeat any threat—stronger/thicker armor, active armor, crew modules, etc. The result—another billion dollar loop. Why are we hung up in this loop? There are many more options to fighting the war.

How have we fallen into this paradigm? For many years, the Army's warfighting doctrine and guidance has been based on the defense of Fulda Gap (Figure 14). It was the battle of the dinosaurs (tanks), slow moving front, armor on the front of the vehicle, not the rear. We talked of creating traps. But this frontal doctrine is based on centuries-old technologies. (The knights fought this way, the war of the longer lance.) We still line up across minefields. We need to change and not go where the minefields are.

We fought Vietnam without the use of big vehicles. Yet we say we need them. The most important change as a result of Desert Storm is that we no longer accept casualties (Figure 15). The doctrine of dinosaurs firing five rounds and then you're dead is not acceptable. The logistics demands of these large vehicles prolonged the war and then in the end they were almost not needed. Additional Apache and A-10 attacks could have killed the same number of tanks, permitting us to go in with light vehicles to

DETECTION - DETECTABILITY
A VICIOUS LOOP

- The future sensors folks showed us that detection technologies will continue to improve by big factor each year.
- The LO technology talks showed us that improvements in detectability have serious limits.

CONCLUSION:

It will take many billions for each time we go around this vicious loop.

CHART 2

Figure 12. Detection-detectability.

ARMOR - ANTI-ARMOR
The Second Vicious Loop

- The anti-armor people can demonstrate that there is an unbounded set of possibilities for penetrating any shell.
- The armor people can demonstrate that there are many ways to defeat any threat.
- It takes many billions of unavailable dollars to go around this loop one more time.

CHART 3

Figure 13. Armor/antiarmor.

THE FULDA GAP PARADIGM

- Attack or repel an attack front-on in a constrained space - Slowly moving battle front
- Army's role almost centuries old doctrine. 70 ton tanks appropriate vehicles
- Only Army aviation makes it look modern - faster action, small scale (some kilometers), diffused front.
- Infantry follows in lightly protected vehicles.
- Air Force assures air superiority - doctrine not dependent on it. Losses are assumed massive.

CHART 4

Figure 14. The Fulda Gap paradigm.

THE DESERT STORM PARADIGM

- Big losses were not acceptable from the start.
- Range of battle demanded biggest logistics preparations ever. (Fuel lines, water lines, resupply trucks,...). 6 Months
- First deviation from the toe-to-toe doctrine.
- Massive Iraqi line first dispersed by missile -- air power.
- Tanks almost too slow to get to the action -- aircraft herded enemy into the M1 columns.

CHART 5

Figure 15. The Desert Storm paradigm.

retrieve and transport the prisoners of war. The terrain gave us the opportunity to go around the battle lines and minefields they had prepared. This was the first doctrinal deviation from our Fulda Gap toe-to-toe doctrine. Yet, the tanks were almost too slow to get into the action.

What are the future rules of engagement? (see Figure 16) We are not going into war if we cannot guarantee low casualties. I do not believe we will go in where there is a chemical or nuclear risk. Should we be nuclear hardened? Probably to some extent, as we may need to go in for cleaning up. In the future, reliability and speed of logistics will be critical. During Desert Storm, we laid some 600 miles of oil and water pipeline. Look at all the work force back to the manufacturer. We need to develop ways of cleaning up and reducing this logistics trail.

If we can improve fuel economy (Figure 17), look at the major reduction in the logistics trail. The logistics trail is an exponential function. We need to develop a vehicle that is so reliable that you can carry most of the spares with you. The ideal reliability is almost no logistics trail—the vehicle that never or almost never fails. If it does you destroy it on the spot; never think about repairing it. We could have lost the Desert Storm war because of the time it took us to build up this logistics base. We must have redundant communications. We are trying to fight a combined arms war, which will require massive air to ground and ground to ground communications. Because targets may be fleeting, we need a high-resolution IR system with both zoom and replay capability. That way crewman can review possible targets or even ask others to review potential targets. Precision air drop needs to be developed. It will make for a leap ahead warfighting technology, and further serve to reduce the logistics trail, since supplies will be delivered where they are needed, eliminating or reducing the need for storing for subsequent ground transporting.

In summary (Figure 18), we thought of the technology war, built the better dinosaur. Now is the time to stop building dinosaurs. We need to think of technology in terms of the information war, the logistics war, and doctrine flexibility. If we win the information war, then we might not need armor or signature control. In the detection war, sensors will win, so don't worry about signatures. Detection time and discrimination are the keys.

We can not give the enemy 6 months to get ready; we've got to hit and hit hard. The logistics war will be won by those who do the most to reduce the trail. Doctrine has changed—toe-to-toe warfare is dead. If we work on the information war, the logistics war, and doctrine flexibility, the answers we get can make the national defense affordable.

WHAT ARE THE FUTURE RULES OF ENGAGEMENT?

- If we cannot gurantee low casualties, we will not fight (see Bosnia).
- We will never fight a set-piece battle across mine-fields.
- The ground war will follow the air war.
- Deep strike will diffuse the battle area.
- Reliability and speed of logistics trail will be most important.
- Ground forces do not necessarily have to face heavy armor.

CHART 6

Figure 16. What are the future rules of engagement?

WHAT'S IMPORTANT FOR FUTURE GROUND VEHICLES?

- Speed, Range, and Fuel Economy.
- Ultimate vehicle reliability.
- All night/all weather operability.
- Light ballistic survivability.
- IR survivability.
- Redundant communications (Air-to-Ground, Ground-to-Ground).
- Quality navigation systems.
- High resolution IR visibility with zoom and replay.
- Precision air-drop resupply.

CHART 7

Figure 17. What's important for ground vehicles?

SUMMARY

- We thought of the technology war.
- Now we need to think of the technology in terms of:
  - •• the information war
  - •• the logistics war
  - •• doctrine flexibility
- That can change the answers and make national defense affordable.

CHART 8

Figure 18. Summary.

10. THE WORKSHOP EXPERIENCE

10.1 Evaluations/Comments.

Based on the evaluations (see evaluation form, Appendix D) received, the participants regarded the workshop as a very good vehicle for generating new ideas. They recommended more such workshops to address Army needs and they wanted to participate.

The following compiled/edited comments are noteworthy:

- Have an unclassified workshop so that non-ARL creative folks without clearances (including sci-fi types and toymakers) could be included and dual use potential would be more likely to surface. [We had tried unsuccessfully to include a hydroplane designer and a controls expert.] But have a smaller group.

- A workshop with a narrower focus might work better or, prior to the workshop, have small specific area meetings to determine the principal issues to be included in the workshop by fewer people/presentations. [The latter seems more attractive in that one of the big goals of the workshop was potential synergisms which might surface when folks involved in different areas were brought together. John Lewis, the engineer responsible for FMBT designs at TARDEC, noted that it was the first chance he had had to meet with structures and armor folks at the same time. Typically researchers are fortunate to gain an understanding of one area, let alone concern themselves with others.]

- There should have been more illumination of the problems in a specific area, not on present solutions.

- Perhaps open forum brainstorming instead of the gradual, private submission of ideas on cards. [This could work very well, given at least one person entering the ideas in a computer for immediate reflection on a large screen. In retrospect, a combination might work well; have cards submitted during the technical presentations so that folks don't lose ideas, then have an open forum. With fewer folks and ideas it might be more manageable.]

- Structure and armor were covered much better than signatures. [Scheduled speakers changed at the last minute, and few signature folks were able to stay for the brainstorming and presentations.]

- Have a contractor review a specific technology within the government, industry, and universities to establish the state of the art, the experts, and possible dual use opportunities. [This would seem to be a good idea for those exciting, new technologies which don't already have a military focus and therefore are not well represented in the laboratory.]

- Invite one or two recognized experts in Land Combat Logistics for a future session.

- Invite USAF to speak about AF R & D directions for future technologies for a future session.

10.2 <u>Other Lessons Learned</u>.

Getting ideas: Our worst fears were that very few ideas would be submitted. The problem instead became one of how to capture and manage so many ideas; 85 were submitted. We defined "success" and primed the pump with suggestions (Appendix E), but it may be that with the right group of people this is never a problem.

Classification: This workshop was classified. This may have prevented the inclusion of some innovative thinkers from other disciplines. Having to do it again, we would keep the workshop unclassified. Since the sessions were classified, the videotapes were classified. This became a real nuisance later when summaries and transcripts were being prepared. We plan to have follow-on sessions with much smaller subsets of this group, probably Government only, at least initially. These sessions will have to be classified.

Number of Attendees: Approximately 50. This is probably more than the ideal; in retrospect, a maximum of 10 research presenters and a select group of 20 innovative thinkers would be better.

Invitees: The participants were primarily invited as individuals, either personally chosen by the workshop director or highly recommended by a colleague. They were chosen on the basis of their expertise in a related area or innovative thinking or both. They were personally invited and committed long before the formal letter found its way to them. The most critical element of the workshop is the right people.

Evaluations: An evaluation form (Appendix E) was provided every participant. Written comments were particularly valuable in assessing the workshop.

Videotaping: Videotaping was critical for accurate reporting. The researcher briefings the first day and the presentations the third day were videotaped. However, the quality of the sound varied considerably. In hindsight, we should have requested that video personnel instruct us all in the best use of the microphone, and speakers should have been interrupted when the sound was not clear. A separate microphone should have been made available to those with questions/comments.

Determining which ideas to focus on: In retrospect, the ideas should have been entered into a computer (in a room nearby) as they were submitted. They should have been organized and grouped by the workshop director and colleagues the first evening. Then the submission of additional ideas could proceed the second morning in a more organized fashion. Perhaps voting would not have been necessary in that grouping might have produced obvious focus sessions. The scheduling of the concurrent focus sessions meant that the proponent of the idea sometimes could not attend the session for his idea, often resulting in considerable variation on the original idea.

Facilitator: A facilitating organization, MTL, managed the sessions, collated and printed the ideas, facilitated the focus groups, and printed the one-page summaries. The MTL facilitators were important contributors to a successful workshop.

Reproducing Facilities: Ensure good, redundant reproduction facilities and plenty of paper dedicated to a workshop. We used a conference room and reproduction facilities belonging to another directorate. This caused considerable grief when the volume of reproduction associated with the workshop resulted in equipment failure.

Publication of Ideas: It is recommended that transcripts be made of the videotaped sessions in which the ideas are presented. The workshop director and idea presenters/submitters should then reduce the transcripts to appropriate summaries if desired for publication.

11. SUMMARY & WHERE DO WE GO FROM HERE

Perhaps of greater benefit than the surfacing of many interesting, near-term and far-term ideas was bringing folks from the structure, armor, and signature disciplines together. Several participants expressed gratitude for the opportunity to talk across disciplines for the first time. The Wrap-up elicited the need to address future concepts in an integrated fashion and the call for multifunctional uses of structures. Note the cohesion between these sentiments and the comments in sections 8.2–8.4. As part of ARL's support of TARDEC's AVT TLD and FMBT ATD, many of these notions will be considered in follow-on sessions involving a Government subset of this workshop gathering, and John Lewis, TARDEC, who is responsible for FMBT design iterations. At such sessions, these workshop ideas will be surfaced for consideration, and where there is potential, the necessary experts will be invited to participate.

It is also our plan to share these ideas with appropriate folks in ARL and the RDECs. Will reaction to these ideas prove that we should leave it to the experts; i.e., don't ask laymen? If so, there should be a vehicle for anyone else with an idea in another area of research to submit the idea to the area and request discussion and response.

Dr. John Frasier, DE, WTD, ARL, requested "momentum vectors"—research areas deemed of highest priority—in his address to the workshop. Almost across the board in the ideas submitted was the need for materials research. In second place was the need for higher density energy storage.

In specific areas the workshop group suggested the following:

- Structures: Investigate low-cost titanium.
  Consider embedded, protected crew capsule.

- Armors: Mature current advanced armors; integrate with composite vehicles.

- Signature: Integrate structure, armor, signature better during concept (no "boxes" on top of LO). Address the need for more electric power.

- Propulsion: Investigate materials which have potential in providing higher density energy storage and those which could enable an adiabatic engine. Address the need for more electric power.

- "Good tech base" in order to develop fundamental understanding.

Realize that the structures and armors areas had more voices than the signatures, propulsion, and lethality areas in the above deliberations.

It was recommended that a ground-air warfare workshop be held for researchers. Many attendees voiced the concern and need to better understand military doctrine and operations, particularly as it may be changing as a result of the downsizing. Representatives from the U.S. Army and AF should be invited to explain future operational concepts, and R&D scientists from the U.S. AF should be invited to explain their research thrusts.

A workshop with wargame modelers was recommended. There was concern about the representation of new technologies in decision-making wargaming exercises with considerable diversity of opinion. Should we even want future technologies represented? Do we make every effort to ensure that a future technology is accurately represented in the most influential wargaming code? Or do we stand tight and state that we will not burden new concepts with the need to justify them in a full systems context? Does the lack of complexity in current wargaming models mean that we must not allow a future concept to be judged/destroyed on this basis? ". . . you can inject Buck Rogers technology into the wargame, but they won't change tactics." Logistics was deemed to be critical according to Dr. Elber's talk and the community appraisal, but do the wargaming codes accurately handle logistics? The point was made that Tech Demos have killed or severely damaged several promising technologies because they did not work perfectly for the Tech Demo.

There was also a diversity of opinion on including man in the loop when it comes to judging a new technology. There is an existing proposal that ARL researchers, turned soldiers, will play in the interactive wargames, gradually infusing advanced technologies, gradually changing tactics, hoping to prove the value of new technologies with the wargaming results. "Doesn't the man need to be involved so that learning can occur (hence, perhaps a change in tactics)?" "If you want to evaluate technology you don't want a man in the loop . . . you want an objective model."

Other Points: Given the communications capability we will have, how can we exploit all the knowledge we will have of our enemy in the context of armor? Dr. Elber's thought-provoking presentation suggests that some innovative thinkers with access to those familiar with our defense systems be presented with various scenarios and, assuming complete information about the enemy and a giant reduction in the logistics trail, determine how to successfully accomplish the objectives. The answers might be very different from established tactics and systems.

In retrospect a workshop such as this should have a narrower focus, much more discussion of ideas, and the opportunity provided participants for a thorough investigation of worthy ideas prior to possible publishing. However, this type of workshop enables the participants to open their minds to new and different ways of thinking, to temporarily escape the tunnel vision associated with the focus of our individual research efforts. The camaraderie and excitement generated by considering "blue-sky" notions at this workshop was infectious, uplifting, and a lot of fun.

Finally, will ARL be funded to do "pure" research or will ARL be constrained to do strategic research only? The contributors to this workshop and report request a response from ARL management to this question.

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APPENDIX A:

WORKSHOP AGENDA

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FUTURE TECHNOLOGIES WORKSHOP
WITH A FOCUS ON

STRUCTURE, SIGNATURES, THREAT PROTECTION
FOR A FUTURE COMBAT VEHICLE

AGENDA

Human Research and Engineering Directorate
Auditorium, Bldg. 459

Wednesday, 9 June 1993

0800–0815	Registration, Announcements	
0815–0825	Welcome	Dr. C. W. Kitchens, ARL/WTD
0825–0835	Why We're Here	Ms. Barbara R. Moore, ARL/WTD
0835–0855	Advanced Armored Vehicle Technology	Dr. Lawrence Puckett, ARL/WTD
0855–0920	Designing a Future Vehicle	Mr. John Lewis, TARDEC

STRUCTURAL REQUIREMENTS

0920–1005	Structural Requirements	Dr. Gary Farley, ARL/VSD Mr. Donald Ostberg, TARDEC
	Materials/Processing/Manufacturing/Producibility	Mr. William Haskell, ARL/MD Mr. Dana Granville, ARL/MD
1005–1020	BREAK	

LOADS & TECHNOLOGIES ASSOCIATED WITH . . .

1020–1045	Active Protection	Dr. Andrus Niiler, ARL/WTD
1045–1130	Armament - Gun	Dr. Ronald Gast, Benet Labs
1135–1235	LUNCH at Officers' Club	
1235–1250	Drive Train, Engine	Mr. Jennifer Hitchcock, TARDEC

SIGNATURES & SENSORS

1250–1305	Camouflage, Concealment, & Deception	Mr. Robert Adams, Belvoir RD&E Center
1305–1335	Visual-Shaping, Surface Treatments	Dr. Grant Gerhart, TARDEC
1135–1350	Radar & MMW Signatures	Dr. William Spurgeon, ARL/MD
1350–1420	IR, MMW, Acoustic Signature Applications	Dr. John Bennett, TARDEC
1420–1435	MMW Sensors	Mr. Bruce Wallace, ARL/S^3I
1435–1505	Future Sensors	Dr. John Pollard, NVEOD

1505–1520 BREAK

PROTECTION AGAINST THREATS

1520–1600	Nuclear: Electromagnetic Pulse	Mr. Steve Sanders, ARL/WTD
	Radiation	Mr. Jim Gwaltney, ARL/WTD
	Blast & Thermal Effects	Mr. Richard Lottero, ARL/WTD
1600–1620	Heavy Armors	Mr. Thomas Havel, ARL/WTD
1620–1640	Light Armors	Dr. Joseph Prifti, ARL/MD
1640–1700	Reactive Armor	Dr. Robert Frey, ARL/WTD
1930–2100	OPTIONAL DINNER	

Thursday, 10 June 1993

0800–0810	Comments from Directorate Executive, WTD	Dr. John Frasier, ARL/WTD
0810–0820	Vehicle Construction Techniques	Mr. Samuel R. (Bob) Skaggs, LANL
0820–0840	Flywheel Technologies	Dr. David O'Kain, Oak Ridge
0840–1200	Brainstorm; Reduce to Manageable List Choose Most Promising Ideas	
1200–1300	LUNCH at NCO Club	
1300–1700	Working Groups Address Specific Ideas Proponents Volunteer	

1930–2100 OPTIONAL DINNER

Friday, 11 June 1993

0800–1130 Presentation/Discussion of Top Ideas

1130–1200	Devil's Advocate	Dr. Wolf Elber, ARL/VSD
1200–1300	LUNCH at Officers' Club	
1300–1500	Wrap-up/Where Do We Go From Here?	Ms. Barbara Moore, ARL/WTD

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APPENDIX B:

LIST OF PARTICIPANTS

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APPENDIX C:

SUGGESTED FORMAT/INFORMATION FOR PROPONENT PRESENTATIONS

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FUTURE TECHNOLOGIES WORKSHOP

Army Research Laboratory

Weapons Technology Directorate

Suggested Format/Information for Proponent Presentations

Description of Idea:
Addresses which area(s):
Payoff:
Risk (high, med, low):
Synergisms:
Suggested Investigator/Organization:
Plan of Attack:
Issues/questions to be resolved (note which is driver):
Transformation into future vehicle concept (requirements in weight, space, power, sensors, data,...):

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APPENDIX D:

WORKSHOP EVALUATION FORM

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WORKSHOP EVALUATION FORM

1. Workshop as a vehicle for generating new ideas? excellent fine poor

   Better vehicle would be—

2. Would you recommend our holding more such workshops to address other Army needs? yes no

   If 'yes', would you like to particpate in such? yes no

3. Please comment on the following for this workshop:

organization	excellent	fine	poor
facilities	excellent	fine	poor
food	excellent	fine	poor
facilitators	excellent	fine	poor
presentations	excellent	fine	poor
brainstorming session	excellent	fine	poor
idea groups	excellent	fine	poor
proponent briefs	excellent	fine	poor
other	excellent	fine	poor

4. What would you recommend we do differently next time?

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APPENDIX E:

"SUCCESS" AND "STARTERS"

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FUTURE TECHNOLOGIES WORKSHOP

Army Research Laboratory

Weapons Technology Directorate

SUCCESS

Ideas - which aid in deployability - mass, volume reductions

- which enhance mission capability (signature reduction, ballistic protection)

- with possibilities, a lot of holes, a lot of questions for further investigation

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FUTURE TECHNOLOGIES WORKSHOP

Army Research Laboratory

Weapons Technology Directorate

STARTERS

o Tunable properties - material which provides, in turn, signature reduction (changes shape, color, luminescence, temperature), ballistic protection, structure? (use recipe 1 for arctic; recipe 2 for desert, recipe 3 for medium threats, etc.

o Can we redirect energy? Convert gun recoil, vehicle vibrations, round impact into electrical energy?

o Replace mass with energy?

o Could batteries, capacitors, fuel cells be integral part of armor?

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MORE STARTERS

115

- o Compressed, lightweight, combat vehicle airdropped; 'blows up' in field; impregnated with local water, dirt, sand, etc.?

- o Could reactive armor (RA) be activated in field, remain nonreactive until then?

- o Adaptive velcro (electrically or magnetically controlled) for attaching armor?

- o Can system sense round, marshall energies to targeted spot & respond?

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LIST OF ACRONYMS

AAVT	Advanced Armored Vehicle Technologies
ACISD	Advanced Computational and Information Sciences Directorate
AFAS	Advanced Field Artillery System
AMSAA	Army Materiel Systems Analysis Activity
AP	Armor Piercing
APS	Active Protection System
ARDEC	Army Research, Development, and Engineering Centers
ARL	Army Research Laboratory
ARO	Army Research Office
ARPA	Advanced Research Projects Agency
ASAC	Active Structural Acoustic Control
ASM	Armored Systems Modernization
ATD	Advanced Technology Demonstrator
AVT	Advanced Vehicle Technologies
CAV	Composite Armored Vehicle
CE	Chemical Energy
CECOM	Communications and Electronics Command
CTSA	Chaotic Time Series Analysis
CVI	Chemical Vapor Infiltration
DE	Directorate Executive
DOD	Department of Defense
EM	Electromagnetic
EM/ET	Electromagnetic/Electrothermal
EMF	Electromagnetic Force
EMP	Electromagnetic Pulse
EPSD	Electronics and Power Sources Directorate
ERDEC	Edgewood Research, Development, and Engineering Center
ESM	Electronic Warfare Support Measures
ETC	Electrothermal-Chemical
FCI	Fuel Coolant Interaction
FFT	Fast Fourier Transform
FMBT	Future Main Battle Tank
HEAT	High-Explosive Antitank
HRED	Human Research and Engineering Directorate
ILIR	In-Laboratory Independent Research
IR	Infrared
KE	Kinetic Energy
LO	Low Observable
LP	Liquid Propellant
MD	Materials Directorate
MICOM	Missile Command
MMW	Millimeter Wave
MOA	Memorandum of Agreement
MTMC	Military Transportation and Mobility Control
NASA	National Aeronautics and Space Administration
NBC	Nuclear, Biological, Chemical

NVEOD	Night Vision and Electro-Optics Directorate
PM	Program, Project, Product Managers
R&D	Research and Development
RCS	Radar Cross Section
RD&E	Research, Development, and Engineering
RF	Radio Frequency
RHA	Rolled Homogeneous Armor
S^3I	Sensors, Signatures, Signal, and Information Processing Directorate
SHS	Self-Propagating High-Temperature Synthesis
SLAD	Survivability/Lethality Analysis Directorate
SOA	State of the Art
TACOM	Tank Automotive Command
TARDEC	Tank Automotive Research, Development, and Engineering Center
TLD	Top Level Demonstrator
TOW	Tube-Launched, Optically Tracked, Wire-Guided Weapon System
USAF	United States Air Force
VPD	Vehicle Propulsion Directorate
VSD	Vehicle Structures Directorate
WTD	Weapons Technology Directorate

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